APPLICATION OF PSEUDO-BOOLEAN MODELS IN WEAPON SYSTEM DESIGN

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by
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ABSTRACT

In warfare, historical records indicate that a larger force usually defeats a smaller force. The U.S. military will most likely fight outnumbered in any large scale conflict in the future. To redress this imbalance, Force Multipliers are used to increase the combat effectiveness of systems. The need to design systems to increase combat effectiveness in a limited resource environment is growing every day. Decision processes for design occur in five areas (material, force structure, doctrine/tactics, training, and the principles of war). This research focuses on a design of a weapon system within the material development area using Force Multipliers as the measure of effectiveness.

This research develops and implements a design methodology for weapon systems that is based on pseudo-Boolean models. The model and methodology developed allows the user to participate in a design process through the specifications and situational/tactical inputs. The Indicators of Force Multipliers (INFORM) Model is developed to implement this methodology to design a main battle tank. The main battle tank, designed by this model, was potentially 30-50% more combat effective than a previous main battle tank.

ACKNOWLEDGEMENTS

I wish to express my deepest appreciation to my advisor, Dr. Robert P. Davis, for his guidance, patience, and advice. His understanding and mentorship was paramount to the successful accomplishment of this dissertation. I am grateful to the faculty and staff of the Industrial Engineering Department, especially to my committee members for their assistance. Dr. Chisman, Dr. Kennedy, and Dr. Kimbler were instrumental in my development while at Clemson. Most of all, I need to thank my wife, Gwendolyn, and my children, Leslie, James, and Katie, for their understanding and patience during the time I worked on this research. Without their love and understanding, I would not have been able to complete this work.

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CHAPTER I

INTRODUCTION

Background

One of the salient dangers facing United States military forces, and the Army in particular, is the fact that they will have to fight outnumbered in future conflicts. Historical records reflect that larger forces usually predominate in battle. It is necessary to reduce or eliminate such force imbalances. Due to current resource limitations, it is not possible nor feasible to match a potential enemy system-for-system or man-for-man. The U.S. military must rely on advancements in technology, enhancements to doctrine and tactics, and other various means to increase the combat effectiveness of its current force. These means, that increase combat effectiveness, are called Force Multipliers. The net effect of Force Multipliers is that a system or a force appears larger due to its increased combat effectiveness capability.

Improvements, to increase combat effectiveness, manifest in the following areas:

- material design (weapon and non-weapon systems),
- force structure,
- doctrine and tactics,
- training and
- principles of war.

Each of these areas are equally important. Internal studies, performed by the Army analytical agencies, point to improvements in each of these areas. Separate studies are performed to determine which of these areas (or combinations of areas) will be accomplished to correct a force deficiency. Figure 1 simplistically illustrates the complex Mission Area Analysis processes that are described in Appendix A. This research concentrates on only one of these solution areas : a weapon system design application.

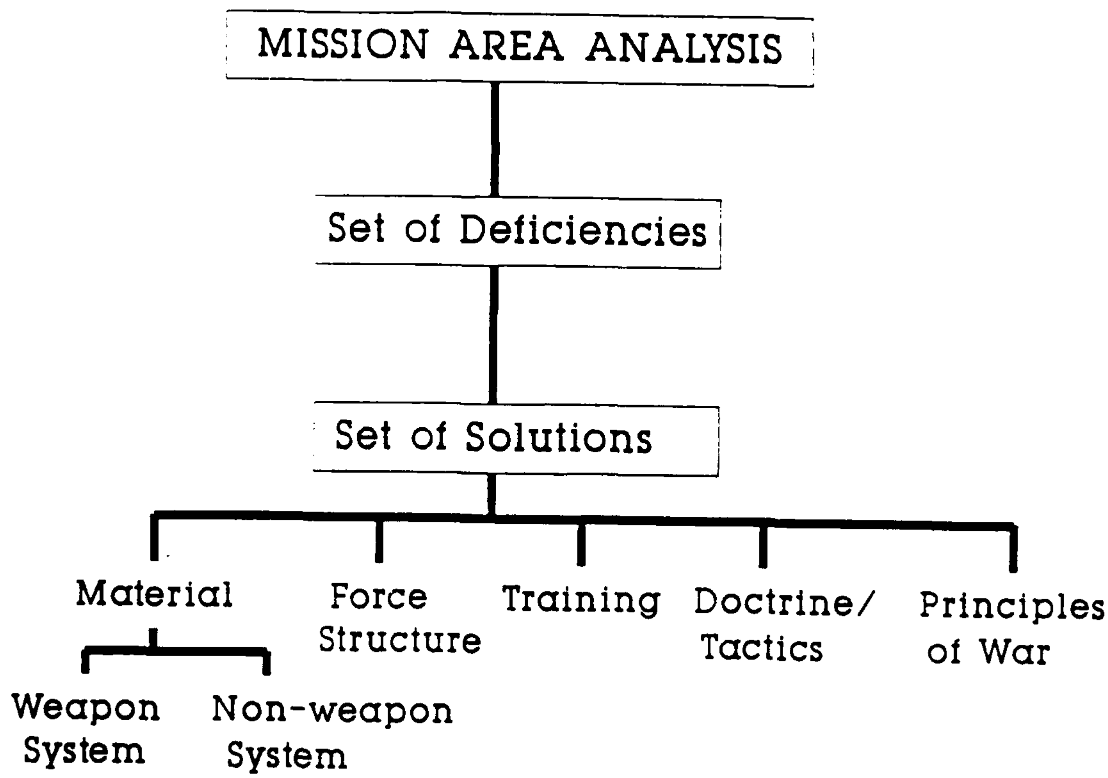

Figure 1. Simplified Mission Area Process

This chapter assumes that the reader has an average knowledge of a weapon system's design. Appendix A contains a more detailed explanation of the background, literature, and weapon system design problem. A glossary of terms is included within Appendix A.

Significance of the Problem

The military budget increases steadily each year. The main increase in appropriation spending shown for the 19901991 Budget was in RDTE [1]. This is due to new material acquisition research, development, procurement, and fielding to correct imbalances in the force. These multi-billion dollar systems have a common basis: a system stems from a need to correct an imbalance or deficiency in a force. Even with this increase request for RDTE funds the Army still cannot meet its goals to develop, produce, test, and field all the new systems. The 1990-1991 budget reduced or delayed production for many new weapon and non-weapon systems.

Production of the Signal Corp's Mobile Subscriber Equipment was reduced by 2 Division sets and production will end in 1991. The AH-94 Apache helicopter procurement was reduced from 72 to 66 per year and its production will end in 1991. Funding was eliminated for tne Army Helicopter Improvement Program and the Improving Recovery Vehicle program. Funding was permitted to continue development of the centerpiece of the army Aviation Modernization Plan, a light helicopter. In addition,

reductions were made to several sustainment programs. These reductions have a great impact on missions to be performed by the military.

The Army's current view is that a trained and ready army is fundamental to deterrence. It is the extent and direction of these readiness and training issues that are of concern. Weapon systems need to be designed such that a weapon system is fundamental to deterrence. A weapon system's design must be complete and cover all possible needs from the outset so design problems do not impede the procurement process.

Current weapon system's design is a compilation of many "wish lists". The material managers and the program managers (PM) of new weapon systems are always attempting to obtain more funds so that increased performance or new components can be added. For example, the Department of Defense (DOD) is currently fielding a new battle tank (M1 Abrams tank) to the force and according to Army Times [4, 15, 69], the PM is seeking upgrades to that system. These upgrades, called Phase II and Block 3, are dependent and ordered (Block 3 depends upon the conversion to Phase II). The current cost of a M1 tank is $2.5 million. The upgrade, to the Phase II conversion, costs approximately $300,000 per tank and then the conversion to Block 3 costs an additional $570,000 per tank. The Pentagon has asked the Army not to try to satisfy all its requirements but to prioritize the improvements. It is estimated that by the late 1990's the Army plans to build a new generation of

tanks combining the features of Block 3 with the newest technologies available. The rapidly changing technologies, in all the fields, are encouraging the developers to implement each new technology without a clear determination of the actual impact on equipment, a system, a force, and a mission.

Statement of the Problem

How can the Pentagon, the Department of Defense (DOD) and Congress make a determination as to which systems, with what technologies, need to be incorporated and fielded into the force? Were those systems, which received a reduced or delayed funding for 1990-1991, the right systems to be reduced? Is a design of a weapon system the design that contributes the most effectiveness to a combat mission? Which new design features should be included within a limited budget? How can a weapon design increase combat effectiveness? This research aims to provide to decision makers an initial step for a design methodology. This design methodology utilizes a common modeling framework to design systems, structures, and procedures. This research focuses on weapon system's design. Weapon system's design is extremely important since it is these systems that bring technology to a lethal battlefield. In the literature, there is not a single methodology to design a weapon system. This research investigates the use of Force Multipliers as the measure of effectiveness (MOE) to design weapon systems. A mathematical model is developed, in terms of

Force Multiplier values, for the design of a weapon system. The Indicators of Force Multipliers (INFORM) Model (the computer implementation of this modeling and design methodology) was created to serve as this design analysis tool. The INFORM Model is a specification and component selection model that has the capability to configure many types of weapon systems while maximizing their Force Multiplier effects.

Significance of the Research

The need for analytical tools to support decision making in the DOD is growing daily. The current literature does not provide any analytical tools for calculating Force Multipliers' effects, or a means to compare effects of different Force Multipliers [18]. For example, during the 1988 Reliability and Maintainability Symposium [58], the U.S. Army stated that the Combat Resilience of a tank is a powerful force multiplier. The Signal community [24, 37] has proposed that the integration of communications, like the Mobile Subscriber Equipment (MSE), is also a powerful force multiplier. How do the force multiplier effects of combat resilience relate to the force multiplier effects of MSE? People involved in a design process are unaware of any technique to quantify their system's design. Leaders must be able to distinguish between these Force Multiplier effects and define a common, quantifiable method so that decision makers can decide which systems are the most advantageous. Within the design of weapon

systems, the designers need a quantifiable method to determine which alternatives for a system's components need to be included in a system. As systems are designed on a common basis, then different kinds of systems may be quantitatively compared. The design methodology developed for this research can be employed for the design of any direct-fire weapon system. Specifically this research has done the following:

1. It defines a generic class of mathematical models for Force Multipliers in the areas of weapon systems, non-weapon systems, training, doctrine/tactics, force structure, and principles of war.

2. It develops a specific mathematical model for the design of weapon systems by decomposition of the force multiplier into force multiplier attributes. These attributes are described as sub-models that can be treated either independently or together.

3. It decomposes "Items" or systems in such a manner that the components map into the force multiplier attributes to contribute to the increasing effects of the potential Force Multiplier.

4. It develops a heuristic procedure to analyze the Force Multiplier in mathematical terms. First, it mathematically defines the Force Multiplier effects into a mathematical statement and secondly, it optimizes this mathematical statement in order to maximize the Force Multiplier effects among limited resource constraints and alternative selection choices for components to the "item".

5. It measures a model's success by illustrating the design of a main battle tank system. The component's Force Multiplier effects are calculated and each component can be shown to contribute to the overall Force Multiplier value for this weapon system.

6. It allows the modeling and methodology applications of the design of a main battle tank example to be extended to any "item", system, procedure, or force.

Structure of the Dissertation

The results of this research are presented in five additional chapters. Chapter II presents the literature review, which reviews the concept of force multipliers and the application of pseudo-Boolean models to weapon system design. Chapter III contains the detailed information defining this problem and presents an assessment and modeling methodology for any "Force Multipliers" that are used to resolve a design problem. Within Chapter III is a simplified mathematical structure developed to analyze and illustrate this technique.

Chapter IV applies this methodological structure to the design of a weapon system. Modeling application techniques and a detailed methodology for applying pseudo-Boolean models to a design of weapon systems are presented. The modeling and methodology is illustrated through an example of the design of a main battle tank. Chapter V discusses the results of these modeling and methodology efforts. The results and some sensitivity (post-optimality) analysis for a main battle tank design are discussed. Additionally, Chapter V critiques the modeling, methodology, and computer performance execution time for an example problem. Chapter VI presents a brief summary of the analysis, conclusions, and observations for the extension of this modeling and analysis research. The appendices consist of additional information concerning weapon system modeling and acquisition, weapon system mathematical functions, the computer model, and the data.

CHAPTER II

LITERATURE REVIEW

The current literature provides little discussion that is specific to the Force Multiplier problem area of this research, but extensive work in other military modeling areas can be related to this research. This review is presented as background literature related both to the research area and to a design problem solution. A majority of the military review for weapon systems is presented in Appendix A. Some literature discussion of weapon system models is presented within the main text and in Appendix B. Applications of pseudo-Boolean models are presented in this chapter to lay a foundation for applying pseudo-Boolean models to a design of weapon systems.

Background

More than a century ago, General Carl Von Clausewitz [91] wrote:

> We think we have allotted to the superiority in numbers the importance which belongs to it:... But to regard it on this account as a necessary condition for victory would be a complete misconception of our exposition; in the conclusion to be drawn from it there lies nothing more than the value which should attach to numerical strength in combat. If that strength is made as great as possible, then the maximum is satisfied...
>
> (Book III, Chapter VIII, p.194)

Von Clausewitz, the founder of the Art of Warfare, saw that numerical superiority is important but that there were ways

to maximize strength other than by shear numbers. The history of warfare reveals that larger forces usually do prevail over smaller forces [7, 18, 28, 50, 63]. Evidence exists to suggest that technological innovations can increase the smaller force to a numerical superiority. The Battle of Crecy (where the longbow enabled the English to defeat the larger French forces in 1346), the Battle of Taupen (where the Piked Spear was first used by the Swiss Infantry to defeat the enemy horseman), and the Blitzkrieg tactics (where the Germans defeated the larger Polish, Dutch, and French forces in 1939-1940) stand as examples where some smaller forces were able to transform their strength to defeat larger forces [28, 50, 63]. More recently, the use of remotely piloted sensor vehicles helped improve the effectiveness of a smaller Israeli force to achieve victory [22]. These few historical references support the concept of the existence of tangible or intangible factors that can increase the effectiveness of a given force.

There have been three related definitions given to the concept of a Force Multiplier. Col. Trevor Dupuy [17, 18] defined a force multiplier as any factor, tangible or intangible, that increases the combat value of a force. Dupuy cites Von Clausewitz's statement, concerning the defense as a stronger form of combat, as indicative that a defensive posture is such a multiplying factor. According to Dupuy, these factors can include such other things as terrain, training, leadership, and morale as well as technology. Col.

Dupuy never clarified his concept of the force multiplier nor did he attempt to define what was meant by the value of a force. No analytical expressions were reported for either of these important verbal expressions.

In 1983, Tan [63] defined a force multiplier as the employment of a technique or force, other than ground maneuver, that increases the combat effectiveness of a given ground force. Tan's implication was that maneuver is not controllable and should not be considered a force multiplier, since bad combat decisions can be more costly to effectiveness than good decisions can increase effectiveness. Pickett's charge at Gettysburg was a bad decision that reduced the effectiveness of his force resulting in the defeat of the Southern forces in that battle. Tan's use of the combat effectiveness concept, that has been defined in military contexts quite often, appears more useful than Dupuy's abstract value concept.

In 1989, Galing [28] published the effects of Command and Control (C2) as a force multiplier. His definition was broader than Dupuy's but not as restrictive as Tan's. Galing defined a force multiplier as a technique, process, or device that causes a change in the current combat effectiveness of a given force. His hypothesis was that command and control was a force multiplier. He showed that command and control could improve the combat mission effectiveness by 30-40% during a highly controlled computer simulation of a National Training Center Exercise. After using simulation to replicate the

exercise, different key combat decisions were made at critical battle times and the results recorded. A panel of typical army experts graded these results on the basis of mission accomplishment and performance. The panel's grading showed that command and control could potentially improve combat results. The simple expression used by Galing was

$$FM=f(FE_1/FE_0)$$

where

FM =Force Multiplier,

FE_1=Force effectiveness after applying C2,

FE_0=Force effectiveness baseline value,

$f()$=Mapping of force effectiveness values.

The mapping used in his simulation was one to one. The values of effectiveness were merely impressions of typical military officers based upon the scenario of the simulation. In his research, Galing stated that there is a need for force multipliers to be quantified and to discover the relationships between different force multiplier effects.

The emphasis in all three definitions is on increasing the force value or force effectiveness. According to army literature [83], combat or force effectiveness is a relative concept having meaning only in comparison to an opposing force. Because combat is fluid in its nature, a unit's effectiveness is always changing. Thus, it appears more feasible to treat system effectiveness as a potential effect rather than examine a few scenario dependent results. Ferguson [24] stated that force multipliers need to be general in their

evaluation because specific scenarios can lead to meaningless overall conclusions, or worse, improper predictions of a new scenario based on an old scenario.

Pseudo-Boolean Model Literature

Literature exists to support the modeling selected for this research. Mathematical programming techniques have been successfully used in design areas similar to that developed in this research. Dogan [14] examined the application of pseudo-Boolean models in manufacturing control systems software design. His six step approach served as a guide to the approaches made in this research. The initial decomposition of systems and the subsequent defining of their non-linear interrelationships are key elements to both research initiatives.

Another similar research was conducted by Scott, Davis, and Wysk and others [10, 14, 53, 64, 66]. Some of the analysis procedures they used in their optimal adaptive control configuration for a given machining process were incorporated into this research.

Again, Davis [10] applied a zero-one integer programming procedure to network protocol. This technique is directly applicable to a system performance scenario. His specification matrix is applicable to any system performance scenario or a comparability matrix of component to component interrelationships. Davis, et. al. [64] employed a mixed integer program to

solve for component selection and specification for a conveyor system. The application of selecting and specifying components in order to optimize a particular objective function is one of the backbones of this Force Multiplier decomposition and weapon system's design by component selection research.

Moody [45] applied pseudo-Boolean techniques to a design of a machine tooling cell. Her technique employed both dynamic programing (stages) and an implementation of implicit enumeration with backtracking. The size of her problem was small enough to allow efficient use of implicit enumeration techniques.

These research initiatives stand as support for applying pseudo-Boolean models to the design of a weapon system. The framework is directly applicable, but none of the solution methodologies conform to the model formulation dictated by weapon system design.

CHAPTER III

RESEARCH METHODOLOGY

Problem Definition

A Force Multiplier is a term used to describe any factor that increase a force's effectiveness [17, 28]. It is almost always used in the acquisition process for any military item or system. Project Managers (PM), Combat Developers, and other associated personnel describe their system to the highest level decision makers as "true" , "potential", or "great" Force Multipliers. Besides material acquisition, the term Force Multiplier has been used to describe new training, morale factors, leadership ability, force structure, and other factors. Currently, Force Multiplier is one of the strongest military "BUZZ" words without quantitative substance [7, 18, 50]. The definitions by Dupuy, Tan, and Galing [17, 18, 28, 63] attest to this lack of substance by their inability to define a Force Multiplier by a mathematical expression. The decision makers hear that "items" are Force Multipliers, so any improved parameter of a system is used to describe a system. The central decision making authority has a seemingly impossible task to compare: the improved firepower of tank A, the enhancements of radio B, the capabilities of radar tracking device C, the leadership training course D, etc. There is not even a clear relationship among these systems. As previously stated, items or systems can lose their funding

either partially or completely. These reductions of funds occur when systems cannot substantiate their contributions. The decision is strictly based upon two factors: the budget and the subjective prioritization of the "items" by a panel of general officers.

This research focuses on part of this issue. One common comparability factor is the Force Multiplier. It defines the contribution of an "item" in terms of its combat effectiveness potential. A model can be developed that will define a design configuration for a system by selecting the components of a system that will maximize combat effectiveness in a limited resource environment. The general approach to this research aims at providing a potential hierarchial modeling framework for component specification and selection models to achieve maximum combat effectiveness of an item, system, or force.

The "Force Multipliers" in this research are defined to have six separate Force Multiplier aspects:

- weapon systems,
- non-weapon systems,
- doctrine/tactics,
- force structure,
- training and
- principles of war.

An "item", that has Force Multiplier effects, can be addressed in one or more of these areas. The process for modeling the potential Force Multipliers is presented in

generic terms so that a system's design can be modeled within any of these six Force Multipliers aspects.

Approach to the Problem

The total scope of this research can be divided into 7 steps. These steps are described below. Each step is addressed in this research.

Step 1. Decomposition by Force Multiplier Type

As a first step in this research, a typical Force Multiplier is decomposed into its sub-levels. The essential levels are defined as weapon systems, non-weapon systems, doctrine/tactics, force structure, training, and the principles of war. During this step the choice (choices) of which Force Multiplier areas to use is (are) established. Figure 2 illustrates a typical "item" that is classified within a force multiplier area.

Step 2. Decomposition into Force Multiplier Attributes

The attributes of the force multipliers are established and defined for use in the model. Further decomposition may be required for specific levels of detail. Figures 3 and 4 illustrate this for the design of a weapon system and its attribute lethality, respectively. These Figures represent the level of decomposition used in this research.

Force Multiplier	Item
Weapon System	Main Battle Tank
	Attack Helicopter
Non-weapon System	Communications Equipment
	Intelligence Equipment
	Computers
Force Structure	2 Corps
	5 Divisions
	54 Tanks per Battalion
Training	National Training Center
	Reforger
Doctrine/Tactics	Airland Battle
	Deep Attack
Principles of War	C3I
	Mass
	Economy of Force

Figure 2. Decomposition by Force Multiplier Type

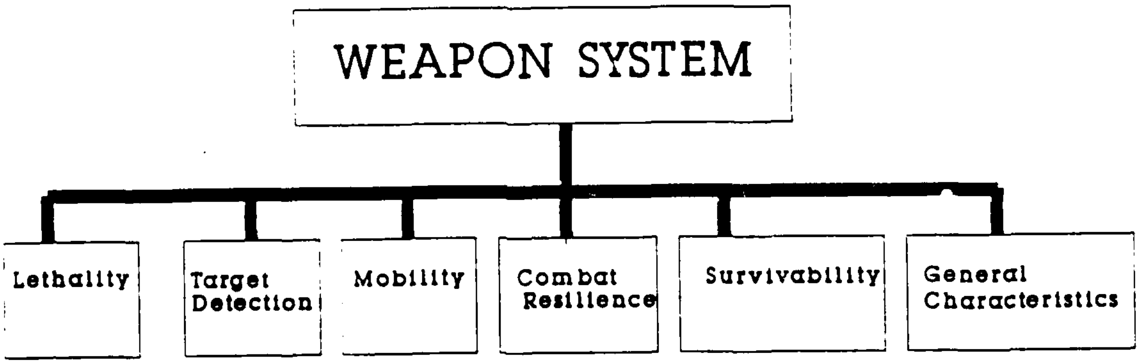

Figure 3. Weapon Attributes

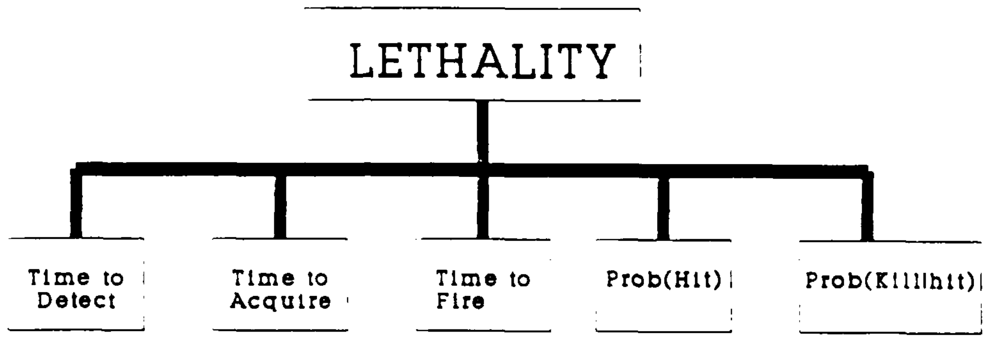

Figure 4. Lethality Attributes

Step 3. Decomposition of an "Item" into Components

An item under study must be decomposed into both manageable and useful components. Figure 5 illustrates a component breakdown for a weapon system that must "move, shoot, and communicate" on a battlefield.

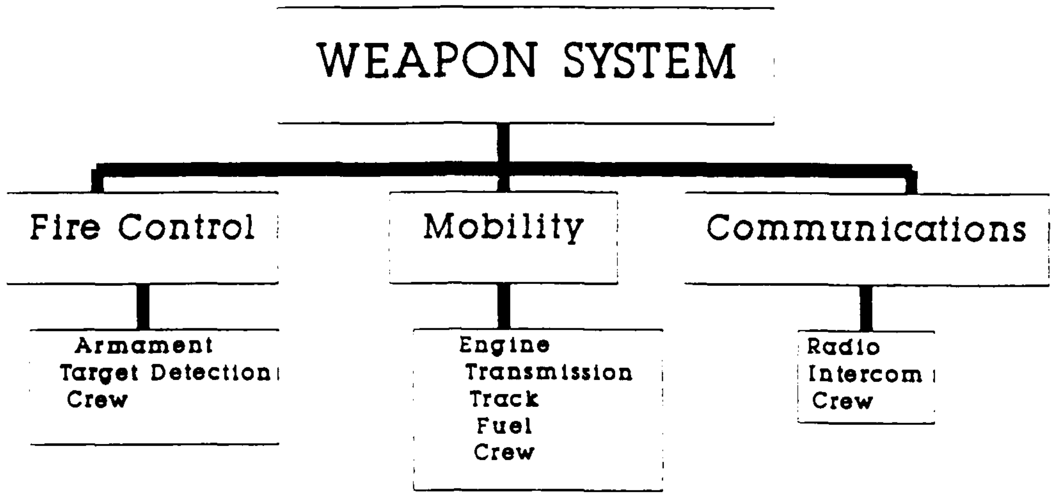

Figure 5. Weapon System Components

Step 4. Definition of Interrelationships

During step 4, interrelationships among a system's components to the force multiplier attributes are defined. An example of these interrelationships is shown, in Figure 6, for a generic weapon system.

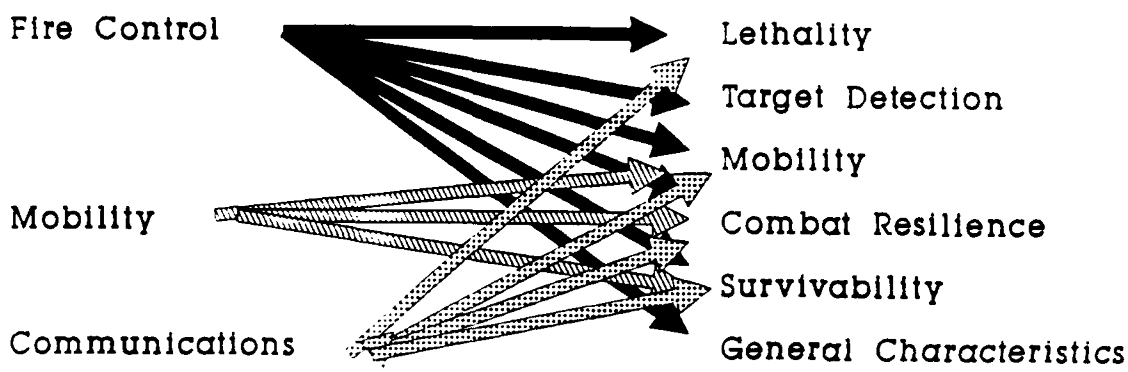

Figure 6. Interrelationship Example

Step 5. Development of a Mathematical Model

This part of the research investigates and defines the necessary criterion function and the constraints that may be imposed in selecting and specifying components to enhance the attributes of the force multiplier. A model is then formulated from the criterion function and the constraints. A solution procedure for the model is developed and implemented. A main battle tank example is developed to illustrate the model and the solution procedure.

Step 6. Sensitivity Analysis

Sensitivity Analysis is essential to examine how the model output reacts to changes in the coefficients and

constraint levels. Sensitivity Analysis is a useful tool for decision support analysts.

Step 7. Extensions to the Research

Extensions of this research are listed and discussed.

Summary

The Indicators of Force Multiplier's (INFORM) Model is developed as a decision maker's tool. The ability to quantitatively compare "items", systems, procedures, force structures, and training, through a common method, is critically needed in the Department of Defense (DOD). The ability to design a system that maximizes its Force Multiplier capability within a specified budget is also critically needed. The current void in the DOD modeling community is filled through an application of this modeling approach. The INFORM Model is a main battle tank design component selection and specification model with the goal: maximize the Force Multiplier potential by the design of a main battle tank in a limited resource environment.

Chapter IV

Modeling and Methodology

Modeling Introduction

In the design of weapon systems, there exist many prominent features, consistent with all weapon systems, that need to be included in a modeling effort. These features are the contributions of the characteristics of a weapon system to the system's performance in targeting and killing the enemy, moving to different points within a battlefield, and communicating. The "Move, Shoot, and Communicate" aspects of a weapon system must be the focus of any modeling endeavor. This research concentrates on the design of a weapon system in relationship to that weapon system's effectiveness on a battlefield. The measure of effectiveness (MOE) is the Force Multiplier value.

The Force Multiplier value is the key focal point of the model. The decomposition of the Force Multiplier value into its five components (as shown in Chapter III) concentrates the modeling effort into relating the attributes of five submodels to the component parameters of a weapon system. Within each of the five submodels further relationships are established. These submodels will be discussed later in this chapter.

Mathematical models for weapon systems were discussed in Chapter II. No models currently exist, within the Department

of Defense (DOD), for design by component selection and user performance specifications. This research bridges the void and establishes a model for DOD use in the design of weapon systems.

Weapon System Applications

Component selection and user specification models, as previously discussed in Chapter II, fit into a class of optimization models. This class of optimization problems has been formulated as a standard linear program, integer program, or specialized integer program (assignment or knapsack problem). Although many problems may fit into these specific modeling formats, the dynamics between the attributes of the Force Multipliers and the component parameters of a weapon system invoke a new view of this class of problems.

The research goal is to maximize the Force Multiplier value of a weapon system based upon its design by component selection and user performance specification. Considering any weapon system, the following general formulation applies:

$$\text{Maximize } FM(X_{ik})$$

subject to:

$$g(X_{ik}) \begin{matrix} \geq \\ = \\ \leq \end{matrix} S_p \qquad \text{Specification Constraints } (p=1,2,\ldots P)$$

$$\sum_{i=1}^{I_k} \sum_{k=1}^{K} C_{ik} X_{ik} \leq B_j \qquad \text{Resource Constraint } (j=1,2,\ldots J)$$

where

FM is a function for Force Multiplier effectiveness,

g is a function of the component parameters,

S_p is a specification for a parameter or set of parameters,

C_{ik} is the cost per ik,

B_j is the limiting Capital/Resource.

Modeling Considerations

Generally, all factors influencing a weapon system's design problem cannot be captured in a usable mathematical model. Thus, it is necessary to examine both specific and generalized modeling considerations that impact upon a weapon system's design model. These considerations simplify or clarify relationships within a model. Once a relationship is established, model refinements are more easily made. The following considerations were employed in this research:

1. The level of modeling decomposition is set at the lowest major modeling subsystem using the terms: move, shoot, and communicate as a guide. Armament decomposition is the gun barrel, mounting apparatus, munitions, and crew. Detection is the set of all fire control/detection items broken into primary and secondary subsystems. Mobility and communications items are grouped to the most related subsystem (for exmple: tracks, shocks, and suspension items are grouped together).

2. The level of complexity encouraged the liberal use of subfunctions within the five major design area of lethality, target detection, mobility, survivability, and combat resilience. These subfunctions further clarify the interrelationships among component parameters and Force Multiplier attributes.

3. The combat resilience submodel is the most general because it is still a new concept and is not well defined.

4. Whenever possible, any previously published expressions or functional relationships are used to relate parameters of components to the attributes of the Force Multiplier.

5. Effectiveness is designated as the measure of effectiveness (MOE) to describe the Force Multipliers. Thus, a dimensionless functional relationship is selected to describe each submeasure.

6. Constructing a model is the best alternative among the modeling choices described by the hierarchy of models. The emphasis is on the flexibility to model the dynamics involved in the interrelationships of the components and their impact on the Force Multiplier value. Constructing models is the most flexible and one of the least expensive methods of modeling.

7. An iterative nature of model construction (Figure 7) is available and it adheres to the earlier simplification assumption.

8. There must be one and only one alternative selected from each system component as part of the weapon system.

9. Models devoted only to overall performance and cost are not effective, due to the large differentiation in cost from component to component, and were not considered.

10. Listing every term in the criterion function and in the constraints is an inefficient modeling technique and is paramount to performing complete enumeration. Thus, the model formulation had to be composed without listing every term in the criterion function and the resource and performance constraints. A solution array containing the alternatives in the current solution is used to activate the different sections of the model.

11. Functions using the solution array are created to ease the solution and formulation burden expressed in consideration number 10.

12. A Force Multiplier is described as the ratio of current effectiveness of a system to the effectiveness of a baseline system.
    FM = (Effectiveness(new) / Effectiveness(baseline))

13. The baseline system is either a similar type system or the same system in a different situation.

14. Only unclassified models and submodels are used.

15. Within the decomposition phase, there are no alternative selections for turrets, armor, or wiring harness available. Therefore, their contributions are fixed within the data of the other components. Their costs are not considered in the modeling scenario.

16. The results of a model do not need to precisely satisfy all the considerations and assumptions. A model should be robust.

17. Galing's [28] results for a Command and Control Force Multiplier value between 1.3 and 1.4 stand as the only comparable Force Multipliers to measure modeling success. Although his values are based upon a panel of military experts interpreting a combat simulation, his results still stand as a benchmark for Force Multiplier modeling success.

A design model for a main battle tank is a formidable task. All the factors influencing a design of a main battle tank cannot be captured in a usable model. The following specific modeling assumptions were employed in this research:

1. A main battle tank is decomposible into the following eleven components: main gun, auxiliary gun, coax machine gun, primary detection, secondary detection, track, fuel, power, engine/transmission, radio, and intercom.

2. The turret, wiring harness, and armor body components are fixed at their current design level. This will not affect the design process.

3. Munitions are included within their gun type. This will not affect the design process.

4. The crew is not considered a design feature.

5. The M60 tank is a baseline system for a main battle tank. It is used to calculate the scaling factors to compute the Force Multipliers.

6. A tank is a representative direct-fire system.

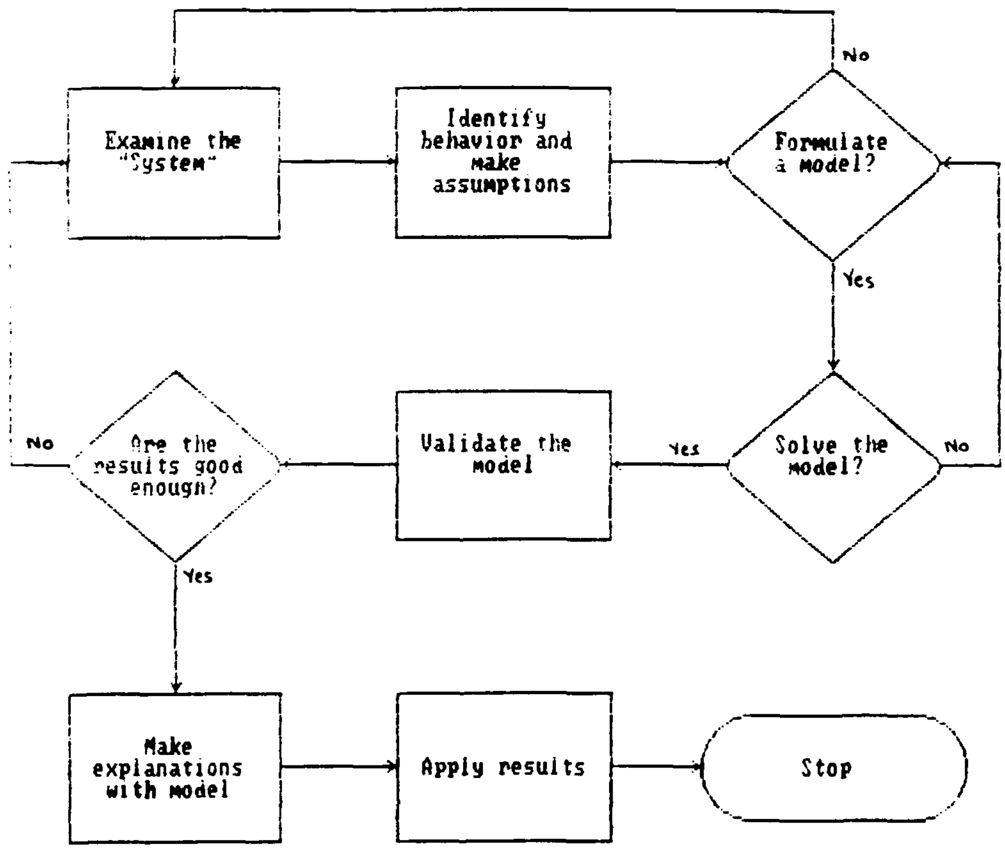

Figure 7. Iterative Models

Weapon System Structure Description

The general decomposition applicable to modeling a weapon system is displayed in Table 1. This table shows the components of the system while Table 2 shows the attributes of the Force Multiplier. In order to model the effects, the relationships between the attributes and the components must be established. Table 3, shows these interrelationships. Applying these interrelationships leads to a more specific formulation, as shown below. A more detailed model can be extracted from the computer model in Appendix C or viewed in Appendix A.

$$\text{Maximize } FM = \frac{FM_L + FM_{TD} + FM_{MOB} + FM_{SURV} + FM_{CR}}{(\text{Number of Components} + Y_1 + Y_2)}$$

subject to:

$$\sum_{i=1}^{I_k} \sum_{k=1}^{K} C_{ik} X_{ik} \leq B \quad \text{(Budget Constraint)}$$

where

FM_L is a baseline scaled function for lethality,

FM_{TD} is a baseline scaled function for detection,

FM_{MOB} is a baseline scaled function for mobility,

FM_{SURV} is a system survivability function,

FM_{CR} is a system combat resilience function,

Y_1 0 Survivability not active,
1 Survivability active,

Y_2 0 Combat Resilience not active,
1 Combat Resilience active,

C_{ik}, B are the cost and budget resource.

The Force Multiplier functions of lethality, detection, and mobility are each only effected by a smaller subset of the components as shown in Table 3. Besides this big picture of the mathematical modeling formulation effort, there are many other smaller modeling efforts used to achieve the criterion function and the constraints. These are described in Appendix A.

Table 1

Weapon System Decompostion

Category	Item	Level
Armament	Guns	Main Auxilary Coax
Target Detection	Sets	Primary Secondary
Communications	Sets	Radio Intercom
Mobility	Sets	Drive (Engine/Transmission) Track (Shocks/Suspension) Power (Altenator/generator) Fuel (type/capacity)

Table 2

Force Multiplier Functions

Category	Effectiveness Function
Lethality	Engagement Rate Function
	Mission Effectiveness
	Obscured Effectiveness
	Kill Effectiveness
Detection	Obscured Detection
	Enemy Detection
Mobility	Agility
	Maneuver
	Mobility of body
	Torque
	Tractive Effort Function
Survivability	Vulnerability
	Detection by enemy
	Hitability
	Emissions (Heat)
	Signal to Noise ratio
Combat Resilience	Availability
	Maintenance ratio

Table 3

Interrelationships

		FUNCTIONS																
		Lethality				Detection		Mobility					Survivability					Combat Res.	
		1	2	3	4	1	2	1	2	3	4	5	1	2	3	4	5	1	2
	A1	x	x	x	x					x			x	x	x	x	x	x	x
	A2	x	x	x	x					x			x	x	x	x	x	x	x
C	A3	x	x	x	x					x			x	x	x	x	x	x	x
O																			
M	D1					x	x			x			x	x		x	x	x	x
P	D2					x	x			x			x	x		x	x	x	x
O																			
N	C1		x		x	x	x			x			x	x	x	x	x	x	x
E	C2		x		x	x	x			x			x	x	x	x	x	x	x
N																			
T	M1							x	x	x	x	x	x	x	x	x	x	x	x
S	M2							x	x	x	x	x				x		x	x
	M3							x	x	x	x	x				x		x	x
	M4							x	x	x	x	x				x		x	x

Submodels Overview

Any weapon system's modeling effort revolves around the five submodels. These are Lethality, Target Detection, Mobility, Survivability, and Combat Resilience. The mathematical functions for each are listed and described in Appendix B.

The Lethality submodel reflects the potential kill effectiveness of the armament components. Although kill effectiveness is the prime function, other subfunctions were developed. These include the effective rate of fire, the potential to accomplish the mission, and the reduction of the effectiveness index due to battlefield obscurities (smoke,

gas, etc.). These submodels are important because they add more detail to the overall function of a system on a battlefield. A more detailed mathematical desciption of each subfunction is listed in Appendix B.

The Target Detection submodel reflects the ability of the detection components to sense, acquire, identify, range, and track a potential target. The major factors, within these component sets, are time and reliability (accuracy). The subfunction for this model is the reduction effectiveness due to battlefield obscurities (smoke, gas, etc.). The Target detection submodel is further described in Appendix B.

The Mobility submodel reflects a systems ability to relocate on a battlefield. Relocation takes many forms: ranging from man packed to self-propelled. The Mobility submodels consider such factors as speed and range. Other submodels used within this section include agility, maneuver, and mobility of the armament, the body, and the detection equipment. Additional submodels for the drive train include torque functions and tractive effort. The inverse of the Vehicle Cone Index (VCI) is used to describe the agility of the system. The inverse is used because a smaller VCI value is an indicator of a better system. Again, a more detailed listing for each is provided in Appendix B.

The Survivability submodel reflects a system's own ability to survive on a battlefield. Major submodels include a systems' vulnerability to the enemy, the ability of enemy to

hit the component or system by the enemy (called hitability), the detectability of the component of the system, the heat emissions signal of a component, and the signal to noise ratio of a component. *Appendix B provides additional information on* the modeling of these subfunctions in the Survivability model. Although survivability is a system function, an attempt is made to partition the survivabilities into the system components. Their sum is equal to the survivability Force Multiplier value.

Combat Resilience is a new concept. It is envisioned that it will entail many more functions in the future than those attributed here. Combat Resilience is limited to system availability and maintenance ratios in this research. The formulas used to establish these two submodels are depicted in Appendix B.

Together these five submodels describe the system's Force Multiplier effects. These submodels are functions of the system's component parameters and the tactical situation provided by the user.

Methodology Introduction

A review of design solution procedures was discussed in Chapter II. None of those procedures were directly applicable to a design of a weapon system. A new heuristic approach was required that could accommodate a weapon system's design process.

This heuristic approach, detailed later in this chapter, combines some of the heuristic ideas used by other pseudo-Boolean researchers [10, 14, 36, 64]. The modules for Reduction, Exclusion, and Inclusion are loosely based upon previous works. The precise execution of these modules is different as well as the execution of the Model Building and Initialization modules.

This proposed component selection and user performance specification methodology is applicable for designing any weapon system. Key parts of this methodology are illustrated using a specific weapon system, a main battle tank. A heuristic solution procedure is chosen over competing procedures because the other basic optimality procedures are deemed too slow and required too much computer memory to be useful as a good, fast decision tool for this particular class of problems.

The solution of this model can be interpreted as allocation of the resource (budget) to the selection of an alternative for each component of the weapon system to maximize the Force Multiplier value. The selection criterion for an alternative is the smallest net loss in Force Multiplier value for the resource savings. In order to employ a good heuristic procedure, assumptions were required in many of the methodological decision areas.

Methodology Considerations

As in the case of mathematical modeling, methodology

considerations are required to simplify the heuristic solution procedure. The following methodological considerations are made:

1. The most expensive alternative for each component category yields the highest performance and effectiveness capabilities. Thus, it yields the highest Force Multiplier value within its component category.

2. Budget is the logical, most restrictive resource influencing the search technique for better solutions.

3. User specifications of performance measures insure that the alternatives, allowed to be selected by the solution procedure, meet the standards set by the user.

4. The user's tactical input values are reflected in the solution procedure.

5. A baseline system is established as a comparative system. This baseline system is the same type or a similar type of system. The tactical inputs are reflected in the baseline system as well as the weapon system under design.

6. Due to the potential size of weapon system models, a heuristic procedure meeting the needs outlined in this research is sufficient.

7. Current component compatibility is insured off-line by means of compatibility matrices. These conceptual matrices are used to help choose the alternatives or alternative sets for the categories of the weapon system.

Consideration number one allows for the establishment of an upper bound (unconstrained limit) on both system cost and Force Multiplier value. Examination of the alternatives for each component shows that the most expensive alternative does possess the highest capabilities and does result in a higher Force Multiplier value. For example, the high technological

advances in armament are leading to the development of direct energy guns. These guns, when completed, would be the most lethal and the most expensive [3]. Generally, it is true that you pay for what you get.

Clearly, the most discussed topic in military related news today is the Department of Defense (DOD) budget and the cuts that the DOD must make to enforce this limited budget. The commercial sector attempts to design and develop anything that the military dreams, but the price tag grows with these dream systems or dream components. The design of a weapon system should achieve the "biggest bang for the buck". Therefore, the budget allocation stands as the major resource constraint restricting the acquisition of weapon systems. The budget is the dominant constraint employed in this methodology.

The user articulates to the designer those capabilities that the weapon system must possess. These design specifications, generally help rule out alternatives which cannot match or exceed the minimum design specifications. The user specifications must be able to remove any alternatives from the potential set that does not meet specification. Therefore, all remaining alternatives considered meet the required specifications.

The user's tactical inputs influence the effectiveness of the components and alternatives considered. These tactical inputs are reflected in the procedure to calculate the Force

Multiplier value for a system's design and the scaling factor for a baseline system.

A Force Multiplier is expressed as a ratio of the change in effectiveness of a system from one state to its original state. The original state becomes the baseline system used as a scaling factor. This baseline system, after being chosen, needs to be decomposed into its five submodels. For example, the baseline system for a main battle tank example is the M60 tank. It is decomposed into similar system components and its Force Multiplier value in each of the five submodels is calculated and is used as the scaling factor. These Force Multiplier values are affected by the tactical inputs and are reflected in the solution procedure.

The Army requires "good", heuristic solution procedures to serve as decision tools or be employed in simulations of combat [68]. Although procedures exist to reach final, optimal solutions, these procedures are slow and take up too much memory to be useful as a design tool for multi-family weapon systems or more complex weapon systems of the near future. Analysts and decision makers require a fast, good solution procedure to assist in weapon system's design analysis.

Component capability is a critical issue. These compatibilities are analyzed by the use of compatability matrices. These compatibility matrices (see Appendix A) show that compatibility, among the system components of a main battle tank, is not a problem. Therefore, it appeared reasonable to consider compatibility outside the actual solution procedure.

Solution Procedure

The implementation of the methodology assumptions coupled with the mathematical formulation culminated in the solution procedure flowchart shown in Figure 8. This methodology is applicable for any general, direct-fire weapon system. There are five main areas to the heuristic solution procedure:

1. data preparation and model dynamics interface-model building,
2. reduction by user specifications,
3. initialization of procedure,
4. exclusion and
5. inclusion.

Data preparation and model dynamics interface consists of a series of interactive prompts. The procedure requires specific knowledge concerning both basic issues and tactical issues. The basic issues include: the number of components, the number of alternatives for each component, and the size of the matrix containing the alternatives for all components. Additionally, all of the user specifications and the situational/tactical inputs need to be read either from an existing file or entered interactively. The analyst's (User) data file is discussed more in Chapter V and Appendix D. In general terms, the user defines values for those situational/tactical variables listed in Table 4. The specifics concerning these definitions are found in Appendix D.

Methodolgy Description

The Reduction module takes the user's specification list and compares the applicable parameters of the component's alternatives to the stated requirements. Those alternatives that do not meet minimum requirements are removed entirely from the alternatives matrix for that component. The purpose of evoking this module is to insure that all the alternatives for the components of the system meet the minimum specifications. This routine contains all the performance constraints for a weapon system design problem. All the current constraints are linear with respect to the performance parameters. Non-linear constraints were not required because the use of component sets removed the non-linear relationships. This routine insures that the final solution meets the minimum performance specifications desired.

Table 4

Situational/Tactical Variables

Budget Allocation
Enemy Probability of single shot kill
Enemy Probability of hit
Width of nominal search path
Area of Operations
Engagement length
Reliability of Mission Accomplishment
Number of systems in overall analysis
Degradation factor for weather or terrain
Obscurity factor due to terrain,weather,smoke
Observer-target rate
Target Density
Range for operations
Visual sweep angle
Alpha rate for engagements
Target-Observer code
Human reliability factor(Crew)
Coefficient of road surface friction
Number of glimpses in a search
Probability that Line of Sight exists
Posture (Open,Defalade)
Engagement type (head,flank)
Time length scenario
Operating time of equipment
Priority of targets
Search Length in seconds

Table 5

Specifications

Armament	Reliability Muzzle velocity Basic load Maximum effective range Power usage Penetration of armor Wavelength
Target Detection	Reliability Wavelength Power usage Effective ranges
Mobility	Horsepower Gear ratio Cruise range Amps available Speed Heat given off Torque Reliability Wavelength
Communications	Electronic warfare Range Reliability Repairibility Power useage

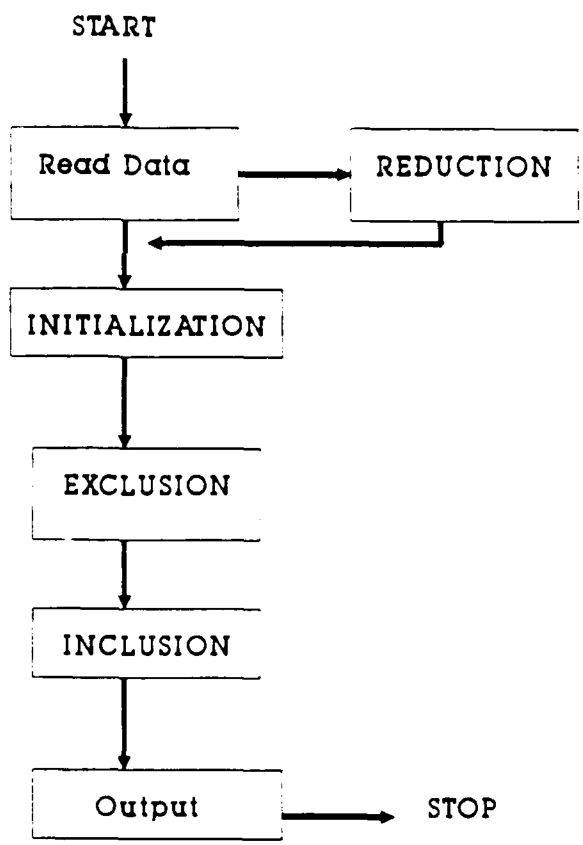

Figure 8. Methodology

The Initialization Module performs two main functions. It provides an upper bound for both the total system cost and the Force Multiplier value. The initial solution is found by selecting the most expensive alternative for each component. Assumption number one is critical in this module. The data for the alternatives are ordered such that they are listed according to cost from least to most expensive. This helps the procedure's speed by not having to search for the most expensive but merely draw it out from the file. The number of alternatives per component is an input and the alternatives are ordered. The procedure can point to a location and extract the most expensive alternative.

The upper bounds for system cost and the Force Multiplier value are held and transferred to other modules within the procedure. After calculating these upper bounds, the Cost is compared to the Budget. If the Cost is less than or equal to the Budget, then a solution(the best solution) is found and the procedure ends. Otherwise, the amount the system is over budget is found by subtracting the Budget from the Cost (equation 1):

$$OB = \text{Cost} - \text{Budget}. \qquad (1)$$

The amount, OB, is sent to the Exclusion Module. Figure 9 gives a more detailed flow of the Exclusion's heuristic procedure to improve feasibility. This routine employs new variables representing the net difference in Force Multiplier value and cost, alternative by alternative, holding all other

components fixed. Figure 10 represents a solution array for a four component example with only component number one varying alternatives while components 2-4 are fixed. This procedure continues until the difference for the last alternative for the last component is calculated:

$$\text{Difference} = \text{FM(current)} - \text{FM(new)}. \quad (2)$$

This difference, equation 2, represents a decrease in Force Multiplier value. Each difference also represents a cost savings, equation 3, since a cheaper alternative is being considered:

$$\text{Cost Savings} = \text{Cost(current)} - \text{Cost(new)}. \quad (3)$$

A sorting routine ranks all the differences (Force Multiplier loss) in the Force Multiplier value from smallest to largest. The smallest represents a better solution than the largest so the ranking is chosen smallest to largest. The cost savings related to each are carried with the ranked differences. Two separate solutions are explored using these ranked differences and their associated costs.

First, a search is conducted for any single difference whose cost saving is greater than or equal to the amount OB. If one is found, the difference is saved for a later comparison test. Second, a cumulative search is conducted. This cumulative search involves summing the differences and their associated costs until the costs are greater than or equal to the amount OB. The cumulative sum of differences is compared to the single search difference and the smaller difference is

taken. The alternatives associated with the selected difference(s) are placed in the solution array. The Force Multiplier value and the system cost for the current solution array are recalculated. This represents the solution offered by the Exclusion routine. If the new system cost is less than the Budget, then a new amount OE is established which represent a new amount to spend, equation 4:

$$OE = Budget - Cost(new) \ . \tag{4}$$

Inclusion, a heuristic routine to improve optimality (Figure 11), is invoked when the result of equation 4 is greater than zero. All the alternatives that have been excluded are now candidates to re-enter the solution array, improving the Force Multiplier value. The differences for all the excluded alternatives are found using the same technique as in Exclusion. All differences and related costs are sorted; this time the sort is by the cost with the differences being carried along. A single and cumulative search are conducted using the value OE as the criterion.

A single search is made for the largest cost less than or equal to OE. The difference is saved from this search. A cumulative search is made, summing the costs and FM differences until adding any more causes the cost to exceed the amount OE. The potential Force Multiplier gains are compared and the largest is implemented. Those alternatives associated with the maximum gain within OE are set into the solution array. This solution represents an improved feasible solution.

The heuristic solution procedure terminates when any of the following conditions exist:

1. Initialization solution is within Budget.

2. Exclusion has each component alternative in the solution array at level 1 (the cheapest alternative) and the total cost still exceeds the Budget. This "inconsistency" termination includes a screen message.

3. Exclusion's system cost solution equals Budget.

4. Inclusion cannot be activated because the Exclusion cost is less than Budget.

5. Inclusion completed and total cost is less than or equal to Budget.

Appendix C contains the computer program for this heuristic solution procedure.

Illustrative Examples

The purpose of this section is to illustrate the implementation of the modeling and methodology through a design of a main battle tank. The Force Multiplier values and the system's costs are calculated and tabularized to demonstrate the heuristic procedure. Any interpretation of the meaning of a design result is deferred until Chapter V.

In order to illustrate this heuristic procedure for designing a weapon system, a main battle tank was selected. The main battle tank was decomposed into eleven components. The first illustration had only four of the eleven components with alternatives. The remaining seven components were fixed at their highest performance level. Table 6 lists the alternatives for the four component example.

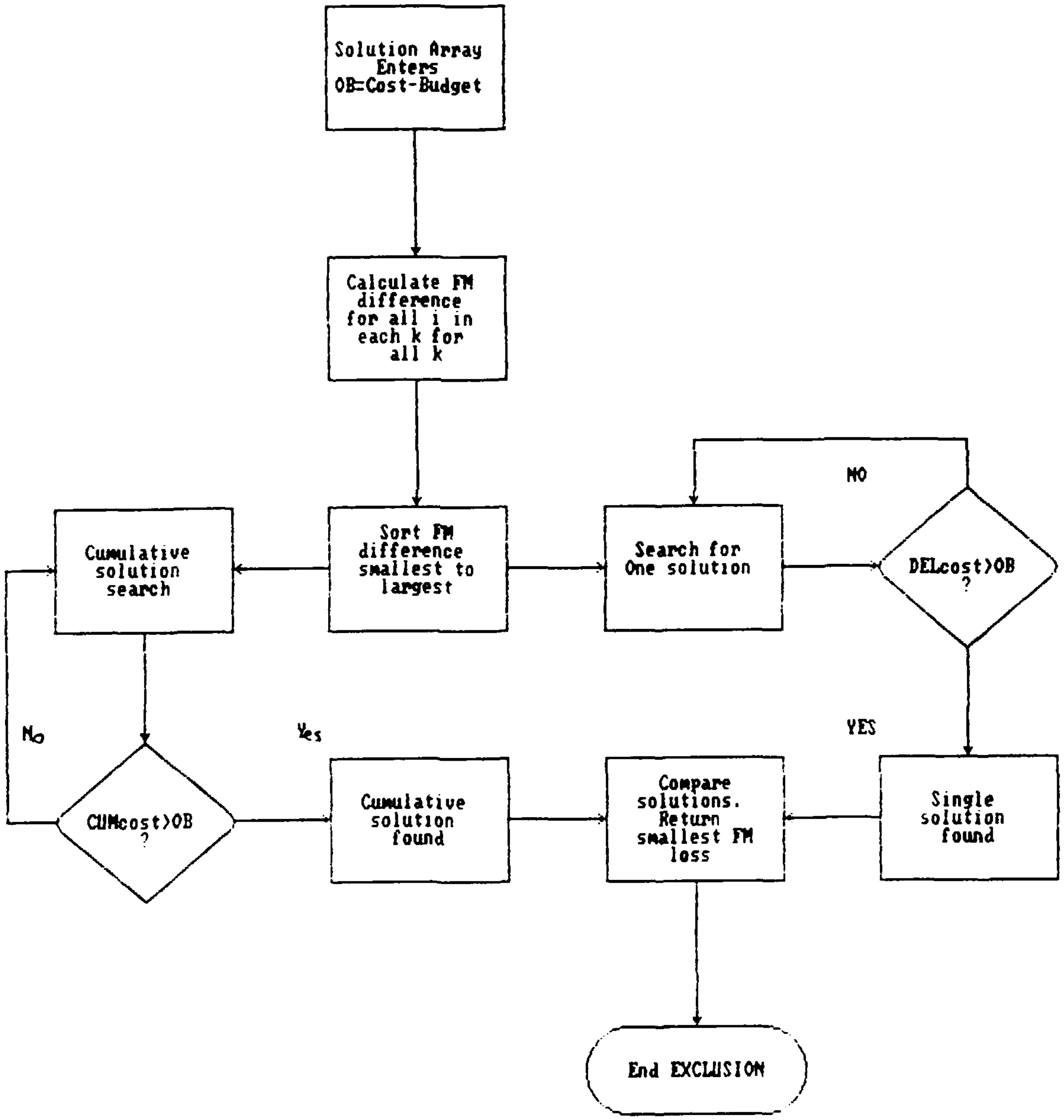

Figure 9. Exclusion

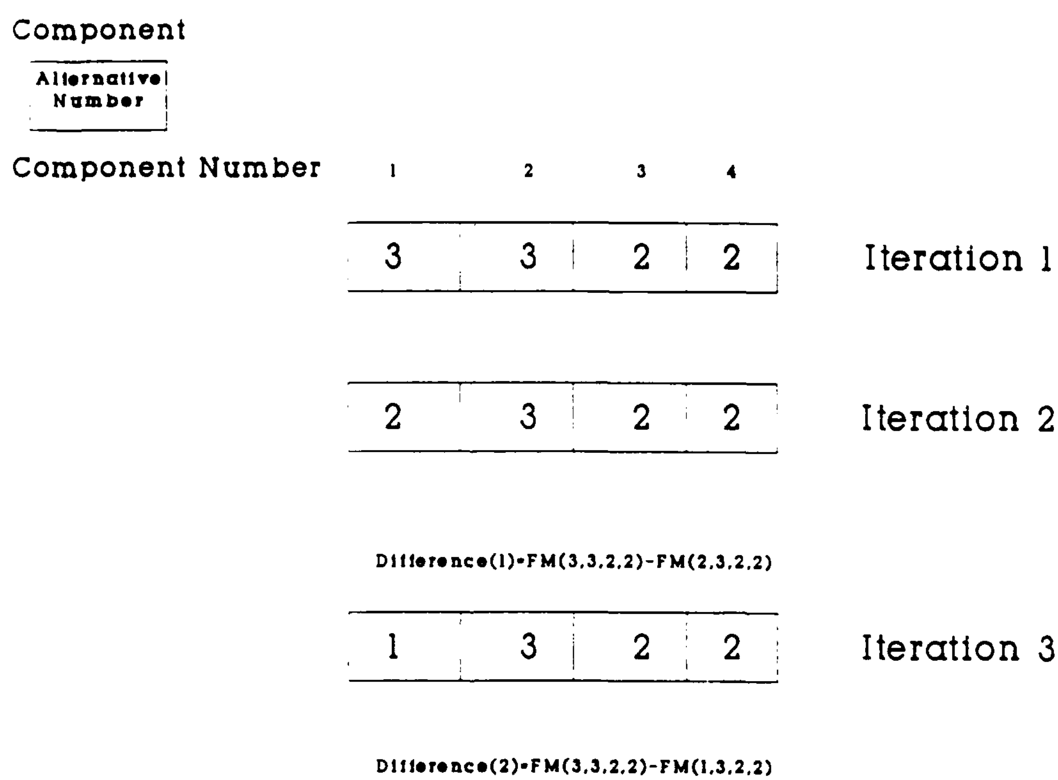

Figure 10. Solution Array

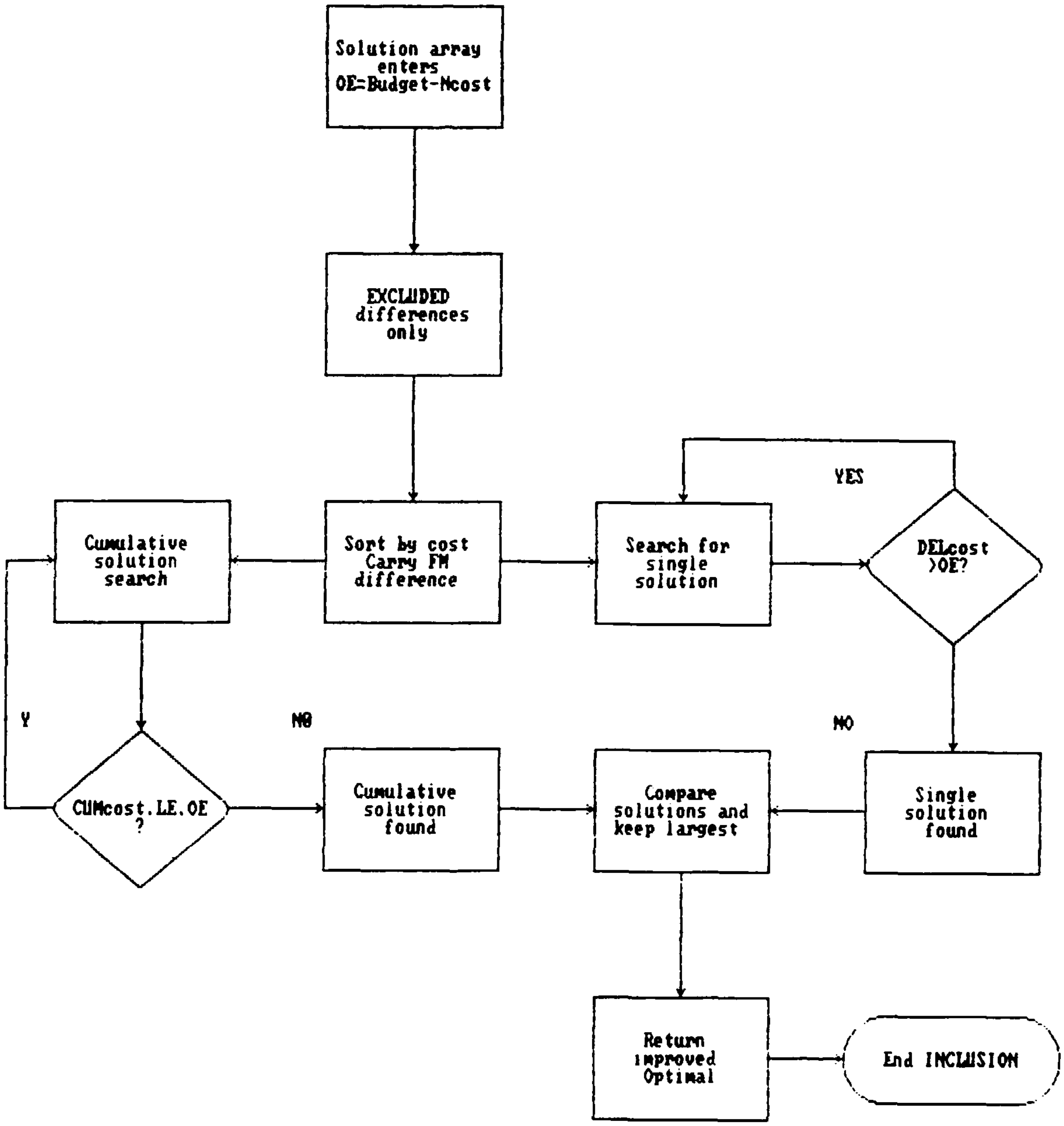

Figure 11. Inclusion

Table 6

Four Component Example

Component	Type	Alternatives
1	Main Gun	105MM, 120MM, 120MM Energize
2	Auxiliary Gun	50Cal, 12.7MM, 30MM
3	Detection set	Set1(Thermal Sight set) Set2(Passive Sight set)
4	Drive Train Set	Set1(1500Hp engine,Transmission) Set2(2000Hp engine,Transmission)

This example was run, twice, with different associated costs and Budgets. The costs and Budget for Cases I and II are shown in Table 7. The budget was changed to accommodate the new costs used in Case II.

Within these examples, all other components are fixed at their highest performance alternative. Further simplification of this example is achieved by activating only the Lethality, Target Detection, and Mobility submodels. The model formulation is shown in Figure 12.

The Initialization routine chooses the most expensive alternative for each component. The alternatives selected for Case I are shown in Table 8. This system's cost is more than the budget allows. The amount over budget, the difference between total cost and the Budget, is $120K. The unconstrained values of cost and the Force Multiplier are $775K and 1.458, respectively. These values represent upper limits for both system cost and Force Multiplier value.

Table 7

Case I and Case II Costs

Alternatives	Case I costs	Case II costs
105MM	60K	6K
120MM	80K	8K
120MM Energized	100K	10K
50Cal	15K	.5K
12.7MM	20.5K	1K
30MM	30K	N/A
Set1(Thermal Set)	95K	95K
Set2(Passive set)	75k	75K
Drive set1(1500hp set)	454.578K	25K
Drive set2(2000hp set)	550K	35K
Budget	655K	121K

Table 8

Initialization Results

K	Alternative	Cost	FM value
1	120MM Energized	100K	1.354
2	30MM gun	30K	1.266
3	Set2 (Thermal)	95K	1.918
4	Set2 (2000hp set)	550K	1.293
	Totals	775K	1.458

The Exclusion routine calculates the differences for each alternative per component as described earlier. Exclusion is constrained by the budget and the routine moves to a feasible design. The design, after Exclusion, is depicted in Table 9. The Force Multiplier value decreased due to lower performance

alternatives being selected. The cost savings was $124,922. This is greater than the $120K that the system is over budgeted. The difference between the Budget and the new system cost is $4922. This amount can be spent in Inclusion. Since none of the alternatives, that were removed, could be added for $4922, the procedure ended with the Exclusion solution as the best heuristic solution.

Table 9

Exclusion Results

K	Alternative	Cost	FM value
1	120MM	80K	1.27
2	12.7MM	20.5K	1.021
3	Set2	95K	1.918
4	Set1(1500Hp set)	454K	1.07
	Totals	650K	1.322

The Force Multiplier value for Case I is 1.322 and the system cost is $650K.

In Case II, the costs and budget are altered to illustrate the entire methodology. This case illustrates the activation of the Inclusion routine in the procedure. The Initialization routine yields an upper bound solution for the Force Multiplier of 1.406 and a cost of $141K. This solution represents a cost that is $20K over Budget. The Exclusion routine is executed as described before. The Force Multiplier value is 1.325 with a system cost of $119.5K. The difference

between the new system cost and the Budget is \$1.5K, the amount which could be spent in Inclusion. The Inclusion routine considers returning those alternatives that had previously been removed. The purpose of Inclusion is to improve optimality of a design. For this example, the choices are either upgrading the main gun, the auxiliary gun, the engine set or some combination with the spending limit of \$1.5K. Inclusion upgraded the auxiliary gun within the spending limit. The Force Multiplier value rose to 1.329 and the system cost rose to \$120K. Table 10 shows the results of Case II. Case II's heuristic terminated after the Inclusion routine while Case I's routine terminated after the Exclusion routine.

Summary

A {0-1} integer, non-linear program is modeled to serve as a decision tool for the design of weapon systems. The modeling emphasis is placed in two areas: the system design mathematical formulation and the five submodels that drive the criterion function. These modeling applications led to a heuristic methodology. The goal of the heuristic methodology is to achieve a "good" and feasible solution to the design of a weapon system's problem. This heuristic procedure is only as good as the results indicate. A main battle tank is used as an illustrative example to show how the methodololgy works.

Table 10

Case II Results

K	Alternatives	Cost	FM value
		Initialization Results	
1	120MM Energized	10K	1.354
2	12.7MM gun	1K	1.027
3	Set2	95K	1.918
4	Set2	35K	1.332
	Totals	141K	1.406
		Exclusion Results	
1	120MM	4K	1.272
2	.50Cal	.5K	1.011
3	Set2	95K	1.918
4	Set1	20K	1.105
	Totals	119.5K	1.325
		Inclusion Results	
1	120MM	4K	1.272
2	12.7MM	1K	1.027
3	Set2	95K	1.918
4	Set1	20K	1.105
	Totals	120K	1.329

<u>Criterion Function:</u>

$$\sum_{i=1}^{3}\sum_{k=1}^{2}(ERF + ME)_{ik}\,X_{ik} + \sum_{i=1}^{3}\sum_{k=1}^{2} OEF_{ik}\,X_{ik}\,\Big(\prod_{k=3}^{4}\sum_{i=1}^{2} OEF_{ik}\,X_{ik}\Big) + \sum_{i=1}^{3}\sum_{k=1}^{2} KE_{ik}\,X_{ik}\,\Big(\prod_{k=3}^{4}\sum_{i=1}^{2} KE_{ik}\,X_{ik}\Big) +$$

$$\sum_{i=1}^{2}\sum_{k=3}^{3} D_{ik}\,X_{ik} + \sum_{i=1}^{2}\sum_{k=4}^{4}(ET + TVE)_{ik}\,X_{ik} +$$

$$\sum_{i=1}^{2}\sum_{k=4}^{4} AGI_{ik}\,X_{ik} + \sum_{i=1}^{2}\sum_{k=4}^{4} MOB_{ik}\,X_{ik}\,\Big(\prod_{k=1}^{3}\sum_{i=1}^{I_k} MOB_{ik}\,X_{ik}\Big)$$

<u>Subject to:</u>

$$\sum_{i=1}^{I_k}\sum_{k=1}^{4} C_{ik}\,X_{ik} \le B$$

$$\sum_{i=1}^{I_k}\sum_{k=1}^{4} PC_{ik}\,X_{ik} \le P$$

$$\sum_{i=1}^{I_k} X_{ik} = 1 \text{ for } k=1,2,3,4$$

$$\sum_{i=1}^{I_k} MV_i\,X_{ik} \ge MV \text{ for } k=1,2$$

$$\sum_{i=1}^{I_k} BL_i\,X_{ik} \ge BL \text{ for } k=1,2$$

$$\sum_{i=1}^{I_k} MR_i\,X_{ik} \ge MER \text{ for } k=1,2$$

$$\sum_{i=1}^{I_k} PK_i\,X_{ik} \ge TGT \text{ for } k=1,2$$

$$\sum_{i=1}^{I_k} RM_i\,X_{ik} \ge RM \text{ for } k=3$$

$$\sum_{i=1}^{I_k} HP_i\,X_{ik} \ge HP \text{ for } k=4$$

$$\sum_{i=1}^{I_k} GR_i\,X_{ik} \ge GR \text{ for } k=4$$

$$\sum_{i=1}^{I_k} MPG_i\,X_{ik} \ge MPG \text{ for } k=4$$

$$\sum_{i=1}^{I_k} MaxSpeed_i\,X_{ik} \ge Maxspeed \text{ for } k=4$$

$$\sum_{i=1}^{I_k} CR_i\,X_{ik} \ge CR \text{ for } k=4$$

Figure 12. Example Formulation

CHAPTER V

RESULTS

The design algorithm is implemented to design a main battle tank with eleven system components. The results of this example are compared to the results of the smaller four component tank example. Both results show that the procedure fixes the component with the largest Force Multiplier contribution to the system and lowers other components performance to obtain a feasible design. In both examples, the target detection components had the largest Force Multiplier value. Other components recieved lower performance alternatives.

The decision to either exclude or include an alternative for a component in the solution depends on two parameters: the Force Multiplier associated with the alternative (FMi) and its cost (Ci). Small changes in either could change the solution. Thc final solution to the model introduced in this research consists of the alternative i chosen for component k in each of K system components. Each component is represented in the final solution. The mix of alternatives provides both a system cost (relative to the K components only) and a Force Multiplier value.

Since the model's function is to aid decision makers in the design of a weapon system by component selection and user performance specifications, the results provide a "good",

feasible system. A good system cannot be obtained if the cheapest system is still more than the budget. The final solution is affected by the user's tactical inputs. These inputs are used to calculate both the system's Force Multiplier and the baseline scaling factor. The user always has the opportunity to investigate solution variations based upon changes in the tactical inputs.

The model introduced in this research is solved using a heuristic procedure. As a heuristic solution, it does not guarantee an optimal final solution. It does provide a very good, feasible solution. In the previous chapter, a main battle tank example is explained in terms of the modeling and solution methodology. A closer examination of the four component example and the eleven component problem is addressed in this chapter and in Appendix A.

Four Component Example

In the four component (Case I-Main battle tank) example only four components (main gun, auxiliary gun, detection equipment, and drive train) have alternatives. The other components, that would be modeled, are fixed at their highest level. The turret, the armor plate, and the wiring harnesses are also fixed since no choices are currently available as alternatives.

The solution procedure yields a feasible Force Multiplier value of 1.3217. The unconstrained upper bound for the Force

Multiplier is 1.458 and the cost is $775K. The system cost is about $650K. The Force multiplier value of 1.3217 is interpreted as follows: If the new tank is used in the situation provided by the user, then it is 1.3217 times or 32.17% more effective than the previous tank system.

Overall, the designed main battle tank lost only 13.63% effectiveness from its most effective value while saving almost $125,000 in cost. The alternatives chosen that yielded this Force Multiplier value are the 120MM main gun, the 12.7MM auxiliary gun, the Thermal sight set, and the 1500Hp engine set. An example of the computer output is provided in Appendix C. Both the unconstrained and the best heuristic solutions and their costs are provided in Table 11.

A value of one in the Force Multiplier indicates that the system is merely as effective as the current system. Thus, in terms of Force Multipliers, the greater the Force Multiplier value the more effective the designed system. As a decision aid, the model provides the Force Multiplier value and cost so that the decision maker has quantifiable justification in order to design or discontinue the design process under the given specifications.

Main Battle Tank Example

In the main battle tank example, eleven components and alternative component sets are in the design scheme. Again, the turret, the armor plate, and the wiring harnesses are

fixed due to the controlled environment. The entire example is described in Appendix A. In this example, all five submodels are activated while only three are active in the four component example. Table 11 summarizes the heuristic design solution to this example.

After the Exclusion routine, the Force Multiplier value and cost are 1.32 and $682724, respectively. This solution represents a 15% reduction in the Force Multiplier and a cost savings of $126,961 from the most expensive cost and is $7276 below the Budget. The Inclusion routine increased the Force Multiplier value 4.43% for an additional cost of only $2539. The final solution is still almost $5000 below the Budget level. There is still room for minor improvements within this $5000 limit.

All five submodels were activated in this example. The Lethality, Target Detection, and Mobility Force Multiplier values represent the influence of a component or component set. The Survivability and Combat resilience Force Multiplier values are more total system oriented, so their value is the cumulative effect of all components (or component sets) in the solution. The contribution to Survivability on the combat battlefield decreased only 1.6% from the upper bound to the final heuristic solution. The Combat Resilience on the battlefield decreased only 2.7% during the heuristic design solution process (see Table 11).

Thus, the system features vary in smaller ranges than do the individual component effects on Lethality, Target Detection, and Mobility. The trend in the Department of Defense (DOD) is to make the system more survivable on the battlefield. These results support this emphasis by DOD in that both components and systems blend together to improve combat survivability.

Table 11

Tank Design Examples Summary

Example	FM_L	FM_{TD}	FM_{MOB}	FM_{Sur}	FM_{CR}	Value	Cost
4 comp.							
Unconstr.	1.31	1.918	1.293	n/a	n/a	1.458	775K
Constr.	1.15	1.918	1.07	n/a	n/a	1.322	650K
FM loss	.16	0.0	.223	n/a	n/a	.136	
Cost savings							125K
11 comp.							
Uncons.	1.31	2.240	1.331	1.424	1.353	1.470	809K
Constr.	1.22	2.240	1.104	1.408	1.326	1.364	685.264K
FM loss	.09	0.0	.227	.016	.027	.106	
Cost savings							124.422K

Computer Execution Time and Memory

This heuristic solution procedure is written and complied in FORTRAN on a microcomputer. FORTRAN is a slower execution language than the PASCAL and C languages. The following execution times (see Table 12) were recorded for the two examples of a main battle tank.

Table 12

Time Comparisons

Weapon System	Components	Submodels	Execution Time(Min:sec)
tank	4	3	:40
tank	11	5	4:50

Even in FORTRAN, the execution of the heuristic procedure is extremely fast. The difference in execution times are attributed to:

1. the number of submodels activated, and
2. the number of alternatives and Components modeled in the system.

The reason that the above affect those execution times so drastically is that the Force Multiplier value changes with every alternative change and is calculated for every alternative of each component in a system. The submodels determine the number of terms in the Force Multiplier calculations for each alternative. These changing Force Multiplier values are used to calculate the differences that guide the heuristic procedure. As more submodels are activated, more elements of the difference terms are required in the Exclusion's difference calculations. These difference equations are included in the program found in Appendix C. The number of alternatives per component and the number of components also increases the number of differences required in the Exclusion process. The

rate of increase is proportional to the number of alternatives added, the number of components in the system design, and the number of submodels activated. Therefore, the execution time increases as these modeling conditions vary.

The procedure, as stated above, was written in FORTRAN for the microcomputer. The computer program is over 1550 lines of programming code and requires about 60K bytes of memory. When compiled, the executable program (.EXE) takes over 100K bytes of computer memory space. The internal data memory storage is over 8.8K bytes. Maximum and liberal use of the Common statement was used to keep this internal memory storage as low as possible.

The data files are maintained separately. The two main data files (Alt.dat and Analyst.dat) for a main battle tank example are contained in Appendix D. The file, Alt.dat, is a matrix of all the alternatives per component in the system and the file; Analyst.dat, contains all the specifications and tactical inputs for the model. Each column of the matrix has a specific parameter associated with its position. This enables the program to point to a particular location to obtain the number required in a calculation. Each position in the user file also has a specific meaning. These are outlined in the data portion of Appendix D. The number of bytes for each file is 4720 for the alternatives and 269 for the user. Several analyst files may be prepared in advance and sequentially used in the model to examine variations in input

parameters. This process is faster than using the interactive method that is also available.

The output of model analysis is transmitted both to the computer screen and to an output file. An example of the output file is contained in Appendix C. The output file can be reviewed, edited, printed, or analyzed by the user.

Currently the entire analysis software can be contained on one 5 1/4" floppy diskette. However, this implementation only contains information relevant to a main battle tank example. As more weapon systems are considered, much more computer memory will be required.

Sensitivity Analysis

Postoptimality, or sensitivity, analysis is an extremely beneficial tool. For this problem, sensitivity analysis has significant value as it allows the user to interact with the model's inputs to measure the effects that variations in component parameters and tactical, input values have on the design solution. In related work with pseudo-Boolean models and heuristic procedures [10, 14, 36, 53, 66], sensitivity analysis was shown to be useful.

The most advantageous relationship between the heuristic procedure and the need for sensitivity analysis is the execution time of the program. The main battle tank problem took under five minutes to obtain the best heuristic solution. An analyst, with a calculator and pencil, would take longer

than five minutes to begin this analysis. It is recommended that, to perform sensitivity analysis, changes be made directly to the data files and that the scenario be analyzed again. The new results can be measured in relationship to previous analysis of the model.

Additionally, there are certain key relationships that can directly affect a solution. For example, the following describe the limited sensitivity analysis.

1. Variations in Resource

   a. A decrease in the Budget resource affects a system design slelection process by choosing the less expensive alternatives that lower the Force Multiplier value.

   b. An increase in the Budget resource allows the alternatives, for components in the solution, to be more expensive; and thus, increase the Force Multiplier value.

2. Variations in Alternative Cost

The variations in the cost of alternatives may change a solution design because alternatives may either leave or enter the design because of their new cost. A lower cost for an improved alternative not previously selected may force it into the solution. A higher cost alternative in the solution may force it to be removed from the solution.

3. Variations in Alternative Parameters

The variations in the parameters affect the Force Multiplier value. An increase in a performance parameter increases a Force Multiplier value. Time parameters are slightly different. A decrease in time results in an increase

in the Force Multiplier value. An increase in the time parameter causes the Force Multiplier value to decrease. The variations in alternative cost and parameter values affect the Exclusion and Inclusion procedures since they both use the change in cost and the change in Force Multiplier value to rank order the choices for the two procedures.

Many weapon systems, and potential weapon systems, have classified data elements describing their performance. Care must be taken to properly use and safeguard this data if employed. This research and related data are unclassified.

Summary

A weapon system design by component selection and user performance specification was modeled as a {0-1} non-linear pseudo-Boolean model and analyzed using a heuristic solution procedure. The heuristic solution procedure offers a good, feasible solution. Of course, implicit enumeration with backtracking could be implemented to achieve an optimal solution. The criterion to measure a heuristic solution is the comparison of its solution to a known, optimum solution.

The heuristic solution procedure relies heavily on the modeling performed to calculate the Force Multiplier value. The modeling results are only as good as the data used to support the effort. The DOD, as well as the army's operational research community, consider obtaining good data as the single, most important contribution to obtaining meaningful

results. Within this research, 75% of the data elements came directly from Army approved sources. Approximately 19% of the data are either interpolated, extrapolated, or estimated from Army approved sources. The remaining 6% of the data used are considered a best educated guess.

To measure a design result a benchmark is established. Galing's [28] solution shows that command and control is a potential force multiplier with a value of 1.3 to 1.4. The solution for the main battle tank example is comparable to Galing's results. The main battle tanks' Force Multiplier results between 1.3 and 1.5 compare favorably with Galing's results.

For the smaller main battle tank example, a complete enumeration procedure was explored [65]. The optimal solution is identical to the final heuristic solution for the smaller example. In the larger main battle tank problem, the final heuristic solution is identical to the M1 Abrams improved design that is currently being designed, built, procured, and fielded [4, 12]. Thus, the heuristic solution procedure was found to yield credible results, useful to a decision maker to design a weapon system.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The general weapon system's design methodology introduced and exercised in this dissertation combines component selection and component/system specification. It is clear that the type of weapon system determines which submodels to activate in a design process. The particular type of weapon system, also, dictates the number of components to consider in a design process. For example, a hand held rifle design would differ from a main battle tank design. The difference would be in the number of system components and the number of submodels activated. The procedure and the INFORM model addressed in this research may be employed in the design of both systems. A main battle tank illustrated the credibility of this design methodology.

In this weapon system design procedure, the specifications and component selection are performed sequentially. The interrelationships among the components, related to a system's ability to "Move, Shoot, and Communicate", affect the design solution. Performance specification are captured in mathematical constraints. These constraints are activated by a designer, prior to the heuristic procedure being executed. This insures that all the alternatives for each component can be selected in a design process, because they meet the minimum required specifications. These specification constraints, the

limiting resource (budget) constraint, and the criterion function (maximization of the Force Multiplier value) form the mathematical model that is used as a design tool. The solution of the mathematical model is reached by performing both the component specification and selection elements of a weapon system's design. The specification constraints insure system performance, while the resource constraint insures that a system's cost is within the required budget allocation. The criterion function acquires the most system effectiveness for the dollar resource.

An important feature captured by the mathematical model is the user's involvement in a weapon system's design. This is accomplished by the user specifying both the specification parameters and the situational/tactical input values. Both sets of input values affect the selection process of the alternatives for the components of a system. Additionally, the user specifies (or accesses from a data file) the alternatives for each component of a weapon system. The number of alternative choices per component affects the selection process as well.

The mathematical model chosen is a non-linear model. This can be a very powerful design tool if all the interrelationships among the components are represented in a model and if a model is supported with good data. The heuristic solution algorithm results show that the procedure yields a credible design, as evidenced by the main battle tank design illustra-

tions. In both examples, the heuristic procedure found a "good, feasible" design.

The model and heuristic procedure add to the knowledge base for military weapon system design, as a design pertains to enhancing the combat effectiveness, measured by the Force Multiplier. This design process is equally applicable to any design problem that fits into this class of component selection and user performance specification problems: non-linear models with performance specification and one limiting resource constraint. This research methodology can be used to design a weapon system, evaluate a predefined system, or compare alternative design strategies.

Contributions

The research performed for a design methodology for a weapon system contributed to the applications and use of pseudo-Boolean models. Inherent in this process is the modeling framework required to achieve a design that maximizes an important issue, the Force Multiplier. The following specific contributions to both the military and academic modeling communities are made by this research:

1. It developed a general modeling and methodology framework, that is applicable to all types of design problems within this class of problems.

2. It developed a non-linear mathematical model to design weapon systems using component selection and specifications.

3. It developed a "good" heuristic methodology procedure to analyze the mathematical models formulated in this class of problems.

4. It synthesized data sources for data acquisition and formated the data files for use in the model.

5. Creative decomposition mapping of the five Force Multipliers into their attributes which map into effectiveness functions was accomplished.

6. Through creative decomposition, a mathematical definition of a Force Multiplier was developed that can be used singularly to give a value to a known system or in a modeling design formulation.

7. A methodology was developed that is used to design a weapon system in order to maximize its force effectiveness, measured for its Force Multiplier value.

8. An analysis tool was developed to evaluate the comparative worth of a design of a weapon system in terms of Force Multipliers.

9. A model was devloped that employs creative mapping of any component's parameters into the attributes of Force Multiplier in order to measure the variations in designs.

10. A microcomputer model, the Indicators of Force Multipliers (INFORM) Model, was developed to design a main battle tank.

11. Systematic data files were developed that allow for accelerated data transformations and information flows used in the INFORM model.

12. A Force Multiplier was quantitatively defined within the context of a design process.

13. A data base was designed for weapon system's design using main battle tank data.

14. Situational/tactical factors were incorporated to have an impact on a design process.

15. This multiplier concept is applicable to any design process where the design improves capability and mission accomplishment. This opens the door for examining any system design.

Extensions of This Research

The following extensions to this research are recommended:

1. The non-linear model for the main battle tank design should be solved to an optimum solution and the results compared to those obtained from the heuristic procedure.

2. The decomposition of the components was limited to an army defined end item. It is clear that these end item's are composed of smaller elements that could be modeled to add higher resolution to the design process. The item levels could be decomposed to lower elements and analysis could determine if this decomposition affects the solution or design makeup.

3. Data is a crucial part of any system design. Data base requirements were established within this research. More extensive data base requirements need to be resolved. The data needs to be collected and stored for alternatives to components for all military systems.

4. The model currently is written for a weapon system: a main battle tank. This tank is a direct-fire weapon system that as specific modeling functions attributable to its being a direct-fire system. This manifests directly into the kill effectiveness calculations and the lethality function. Research and model changes are required to address weapon system design for indirect-fire systems (i.e., artillery). Further modifications would be required to model the design of air based weapon systems (i.e., helicopter gun ships).

5. A 1-1 mapping is used between both force effectiveness and Force Multipliers and between the Force Multipliers and the sub-Force Multipliers. A 1-1 mapping may not be the most appropriate mapping. An investigation into the mapping functions is recommended.

6. The model is written in FORTRAN for a microcomputer. Speed is a critical factor. The model could be ported to another language or languages that would allow for faster operation. The model could best utilized if it were netted so many analysts could use it to perform parallel design functions.

7. This research needs to be continued and extended to areas beyond weapon systems. This methodology and modeling effort needs to be extended to include non- weapon systems, training, doctrine, and principles of war. Completing these other research areas will allow for comparing a design of weapon systems to a design of new training systems. The common base is the Force Multiplier value.

8. Currently, an equal weighting scheme is used in summing the five Force Multiplier submodels. Each submodel value is given a weight of one. The results show that the model fixes the components with the highest Force Multiplier values (Target Detection components) while forcing the others to lower values and costs. Although the model executed as it was designed, it is not clear if equal weighting is appropriate. Is lethality a more valuable Force Multiplier attribute than the Force Multiplier attributed for target detection?

9. The baseline system for a main battle tank design example is the M60 series. The M60 tank was arbitrarily chosen. Baseline systems need to be established for all weapon systems and other DOD systems. These baseline systems need to be decomposed and scaling factors found for each of the major components of the system. These factors can be placed in a data base that could be used in a model.

10. This model can be used to design systems in an iterative procedure. The first run of the model indicates which alternative components need to be included in the system design. These alternatives could have been system sets. Second runs of the model can be made after decomposing a new alternative into its components and enhance its combat effectiveness. To accomplish this type procedure additional work needs to be conducted into data requirements, functional relationships for the new component parameters to map into the Force Multiplier submodels, and establish levels for the model to correspond with component levels.

APPENDICES

Appendix A

Design of Weapon Systems

Background

This section is provided for the reader who is totally unfamilar with weapon system's modeling, design, and acquisition. A weapon system is designed from a Combat Development's prospective through an operation research approach. A glossary of terms and acronyms is provided at the end of this Appendix. This glossary is inclusive for the entire dissertation.

In warfare, historical studies reflect that larger forces usually prevail over smaller forces. The likelihood that the United States conventional military forces will be outnumbered at odds of at least 3:1, makes it imperative that this imbalance ratio be redressed. The U.S. forces would prefer fighting on a force ratio closer to 1:1. To accomplish this redressing, "Force Multipliers" are commonly used to increase the combat effectiveness of a current force. The net effect is that the force appears larger due to its increased combat effectiveness capability. The Force Multiplier concept can be applied to an "item" or system so that appears more effective.

The Combat Developers (CDers) and the Training and Doctrine Command (TRADOC) have the mission to redress these imbalances in the U.S. force as well as any other combat deficiencies discovered by their analysts. The CDers analyze the

deficiencies and, within their study groups, propose alternative corrective actions to their proponent Commanding General (CG). Generally, the CDers are only concerned with imbalances and deficiencies within their area of expertise and mission statement (i.e., Armor is concerned with tanks, Signal is concerned with communications devices). Table A-1 lists the primary branches and examples of their primary mission concerns.

Every two years the CDers perform a Mission Area Analysis (MAA) in context with TRADOC and Headquarters, Department of the Army (HQDA) guidance. During this MAA, the analysts closely examine their branch's combat mission over the next 10-20 years and look for deficiencies in performing their prescribed mission. Figure A-1, depicts this generic process as applied to Close Combat Heavy Mission Area Analysis.

The in-house alternative solutions, Figure A-2, are explored in the areas of material acquisition, force structure, training, and doctrine/tactics (Figures A-3 to A-5) per TRADOC guidance [76,77,86]. The CDers present their information to the decision maker (the CG) and their consolidated recommendation eventually goes to the Secretary of Defense (SecDef) for action and appropriations. Although all areas are illustrated in Figures A-1 to A-5, only a weapon system's design from the material acquisition process is developed as part of this research.

Table A-1.
Primary Branches/Missions

Branch	Mission
Armor	Close Combat with Tanks
Artillery	Fire Support (Howitzers)
Air Defense Artillery	Air Defense
Infantry	Bradley Fighting Vehicle Small arms, Mortars Urban fighting
Signal	Communications systems Computers and Software
Ordnance	Maintenance and repair
Quartermaster	Logistics
Transportation	Transportation and movement
Intelligence	Enemy Detection
Aviation	Air Superiority Air insertion/withdrawal

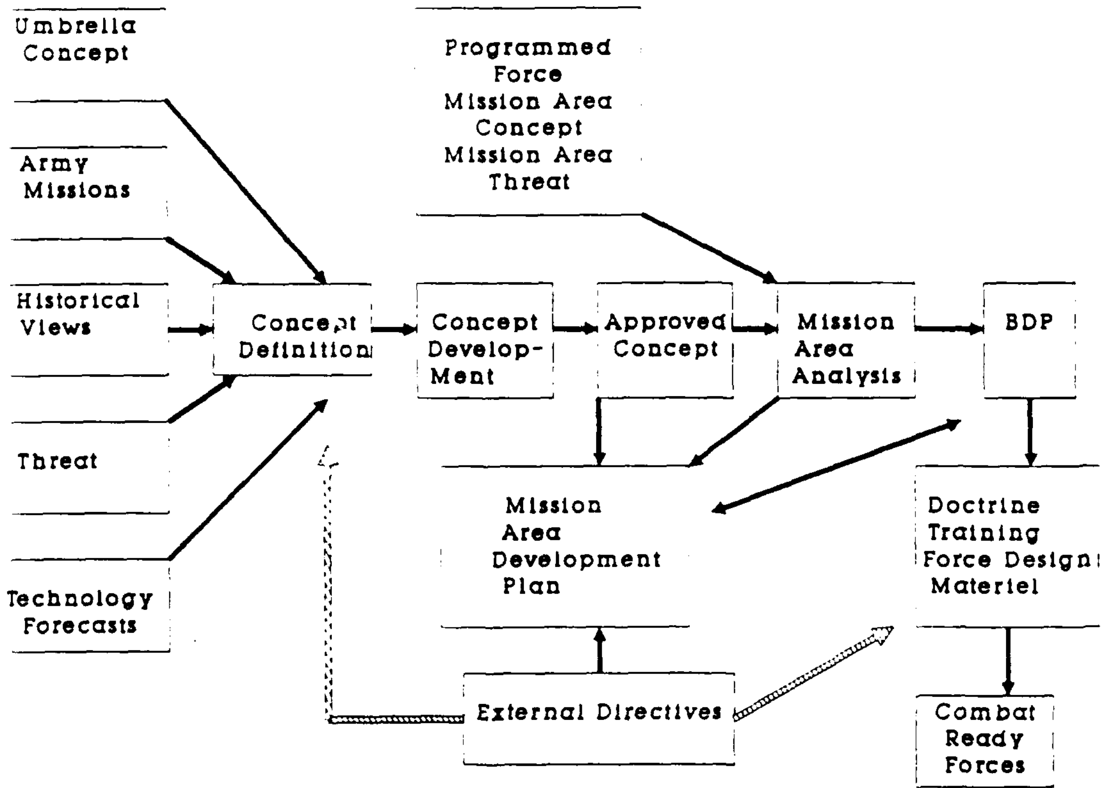

Figure A-1. Mission Area Analysis
(See Reference number 75)

TRADOC has several classified procedures to examine all the corrective actions recommended by all the branch schools. The Battlefield Development Plan (BDP)is one of these procedures. These procedures only deal with solutions and not how to obtain the solution. Due to the classified nature within these procedures and their non-applicability to weapon system design, they will not be discussed further.

The Army focus has changed away from the 100% R&D material approach. The new approach, shown in Figure A-6, has 70% of the solutions still being material solutions. Each branch school's material solution is their branch's "Force Multiplier". These proposed "Force Multipliers" need to be prioritized by the highest army leadership prior to budget submission so that in a limited resource environment only the most important "items" will receive financing. Additionally, a weapon system's component Force Multipliers need to prioritized so that a system's design will be the most effective in a limited resource environment.

The military budget increases steadily each year. The main increase in appropriation's spending for the 1990/1991 Budget was in Research, Development, Testing, and Evaluation (RDTE) [1]. This was due to new material acquisition research, development, procurement, and fielding to correct imbalances in the force. These multi-billion dollar systems have a common basis: the system stems from a need to correct an imbalance or deficiency in the force. Even with the

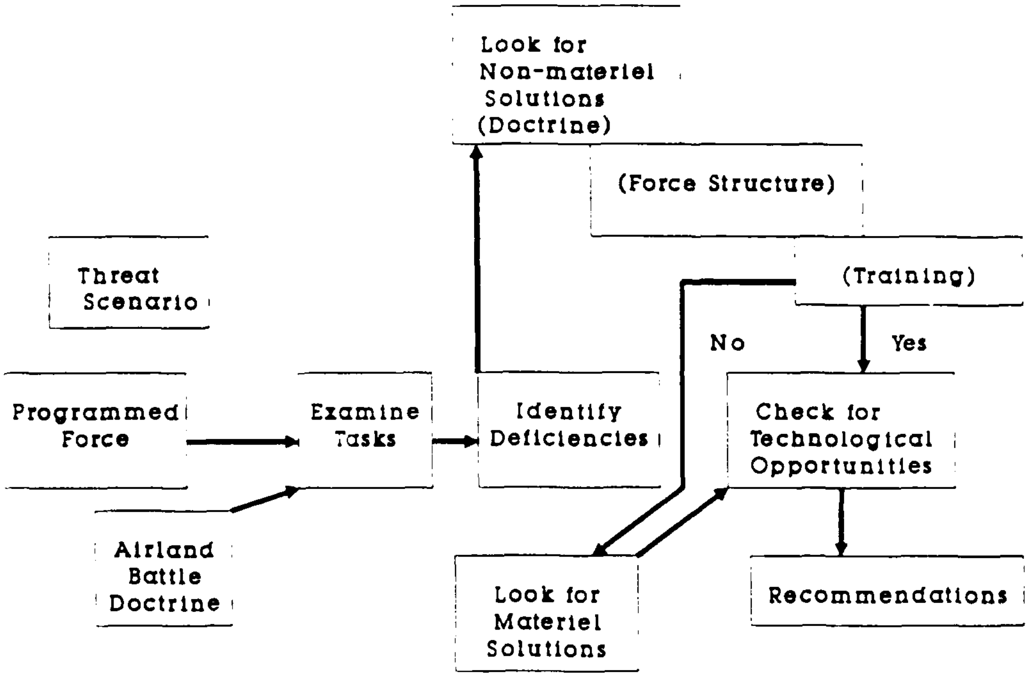

Figure A-2. In-House Alternative Directions
(See Reference number 75)

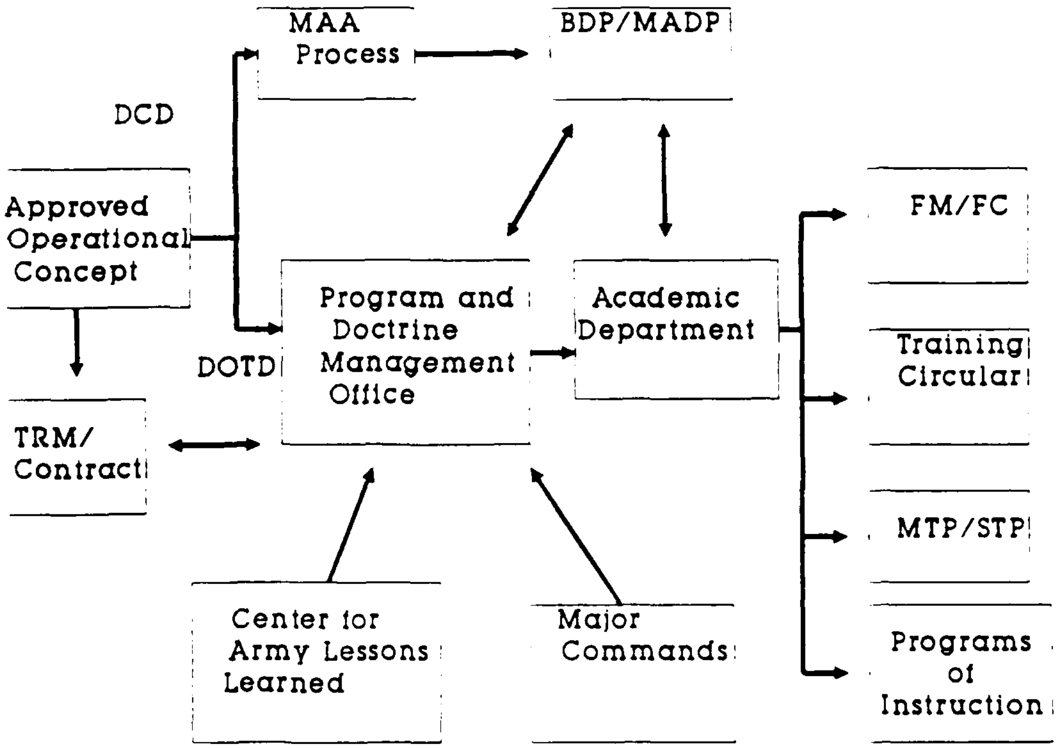

Figure A-3. Doctrine/Training Development
(See Reference number 75)

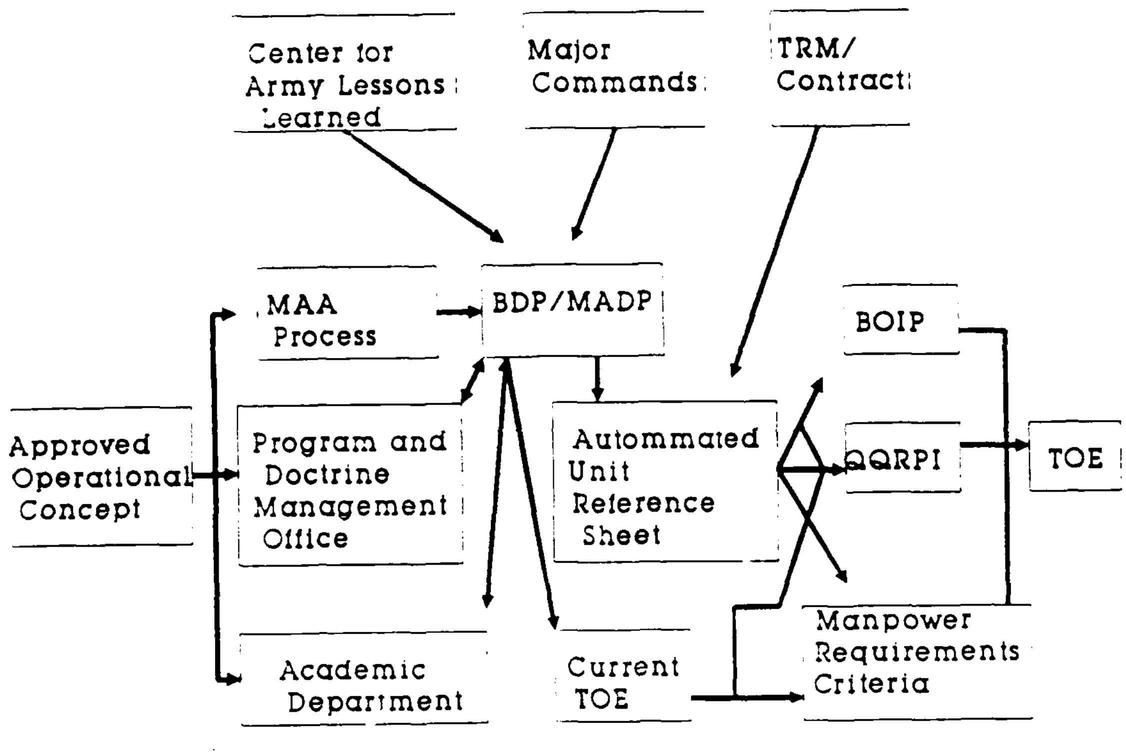

Figure A-4. Force Design/Development
(See Reference number 75)

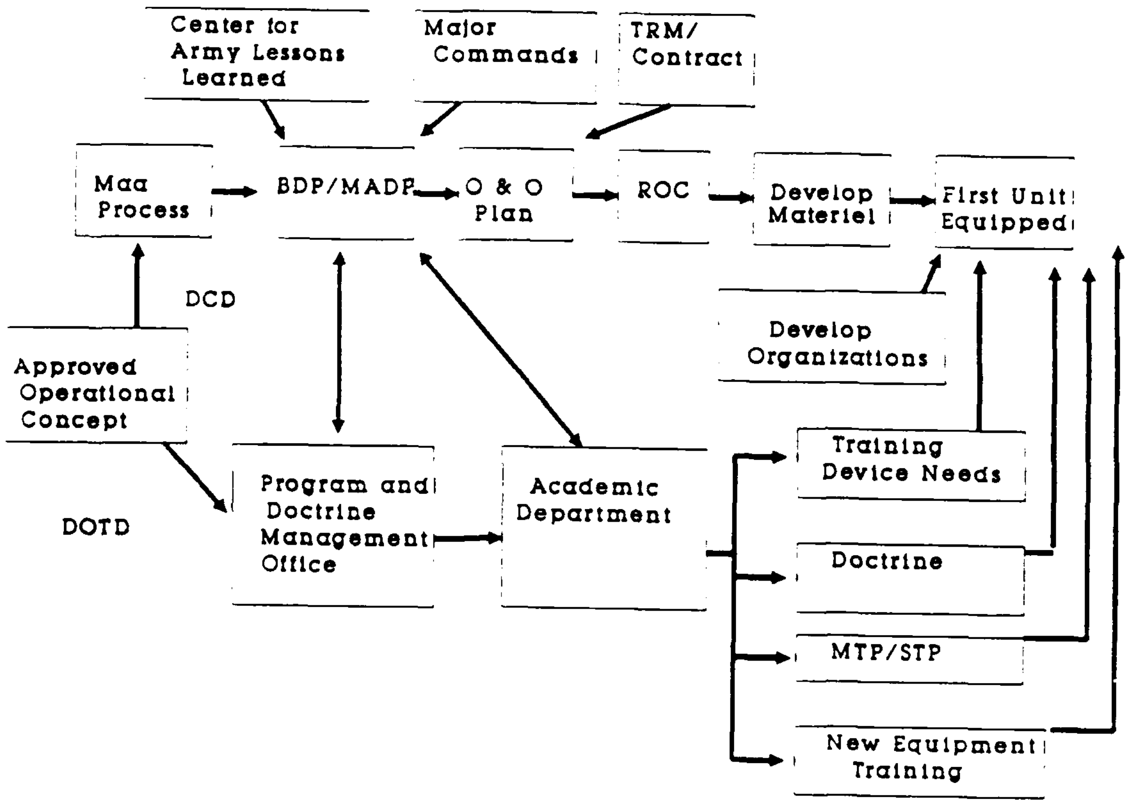

Figure A-5. Material Development
(See Reference Number 75)

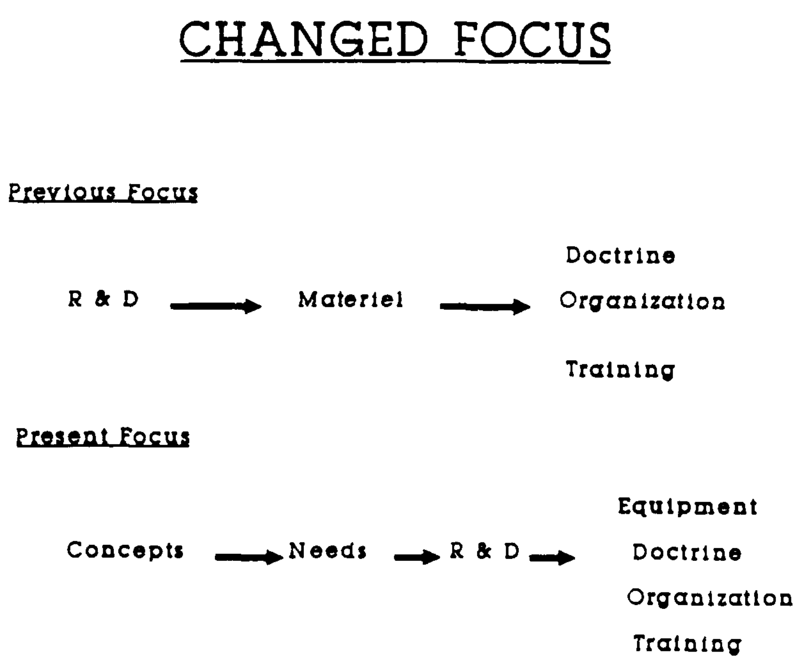

Figure A-6. New Army Focus
(See Reference number 75)

increase request for RDTE funds the Army still cannot meet its goals to develop, produce, test, and field all the new systems. The 1990/1991 budget reduced or delayed production for the following systems:

. Maneuver Control System,

. All Source Analysis System,

. SINCGARS Radio,

. SENSORS for forward Air Defense C2 system,

. UH-60A Black Hawk,

. ADATS,

. Advanced Field Artillery Tactical Data System,

. Logistics over the Shore and

. Stinger Missiles.

Production of the Mobile Subscriber Equipment was reduced by 2 Division sets and production will end in 1991. The AH-94 Apache helicopter procurement was reduced from 72 to 66 per year and its production will end in FY 1991. Funding was eliminated for the Army Helicopter Improvement Program and the Improving Recovery Vehicle program. Funding was permitted to continue development of the centerpiece of the army Aviation Modernization Plan, the light helicopter (LHX). Additionally, reductions were made to several sustainment programs. These reductions have a great impact on supply operations and maintenance. These funding issues are critical in system design and development.

The Army's current view is that a trained and ready army is fundamental to deterrence. It is the extent and direction of these readiness and training issues that are of concern.

Current Tank Problem

The armor school discovered a deficiency in heavy armor during their latest MAA [75]. This led to a re-examination of the main battle tank as a close combat fighting vehicle. MAAs, such as this, led to a new design for the main battle tank. Previously, the M60 tank series received upgrades to correct the deficiencies found within its capabilities. The M60 was at version three, the M60A3. The armor school could no longer recommend upgrades to the M60 version and required a new tank design that was faster, could kill better, and could survive longer on a battlefield. All the new changes led to the development of the a new main battle tank, the M1 Abrams tank.

Current discussions in Congress [2, 4, 15, 69] indicate that the design of the M1 tank does not meet all of the current needs of the armor branch. Modifications and upgrades of components are currently being discussed. The budget allocation from Congress is a limitation to a better design for the M1 tank. If the M1 tank does not receive the necessary modifications, then the Army may require a new tank design by the end of the 1990s [2, 4, 15]. Could these modifications have been found through a good design model?

The design of a good main battle tank is critical to the armor branch's ability to perform its mission on a battlefield. The components that comprise a system must be the most effective for the dollar. The Indicators of Force Multipliers (INFORM) model developed in this research designs a main battle tank such that the components are the most effective for the dollar. The main battle tank is chosen because of it is currently a design issue.

The goal is to design the main battle tank to maximize its combat effectiveness as measured by the Force Multiplier values of the system. These Force Multipliers indicate the effectiveness of the components used in a system design. Component selection and user specifications are used to design a tank.

Literature Review

The current weapon system's literature provides little discussion that is specific to the "force multiplier" problem area or a design of a tank, but extensive work in other military modeling areas can be related to this issue. This review is presented as background literature related both to a design of weapon systems and the modeling aspects of weapon systems. Some of the review is mentioned in the discussion of the mathematical models in the main text and in Appendix B.

Related Weapon System's Literature

In the past, Army analysts have developed and used many models to measure the effectiveness or relative power of a weapon, a system, or a force. The output of these models are the Measure of Effectiveness Indices (MEI) [6, 41]. These MEIs include Inventory count, Firepower potentials, Quantified Judgement by HERO, Weapon effectiveness indicators, and Combat Effectiveness Indicators.

The Inventory count [6, 41, 61] is the most simple and straight-forward index. However, its use as a MEI is not trivial. Its utility is derived from its inherent simplicity of a strict inventory count. The indices are simple sums of the counts of specific weapons and are easy to verify. Lester and Robinson [41] caution the users to consider the counts only in their appropriate class of weapon systems. Inventory count is used often in media to express the imbalance in the force by weapon types between the United States and the Soviet Union [28].

Firepower Potentials have been used by military planners for over forty years [6]. It is one of the oldest methods used in military modeling and was used extensively in early computer simulations [6, 27, 41, 61]. Since then, the firepower scores have been refined to the point where the score develops a single number, and the newer firepower "index" represents the combat potential of a military unit [61]. Stockfish [61] distinguishes between the two by labeling the

score as the military capability or value of a specific weapon and the index as the sum of the scores over the set of weapons that defines the military capability or value of a force. Table A-2 illustrates a typical firepower score/index example.

Table A-2.

Firepower Score/Index Example

Weapon	Quantity	Score	Total
M16 Rifle	500	1	500
M60 Machine Gun	75	3	225
81mm Mortar	28	11	308
155mm Howitzer	18	60	1080
Cobra Gunship	18	70	1260
M60A Tank	54	90	4860
-----------			------
Index			8133

Taylor and Stockfish [27, 61] declare the index as meaningless until the force ratio is established. The force ratio is the ratio of two opposing forces' indices and has direct application to many military modeling efforts. Systems Planning Corporation [27, 94] wrote a refinement to firepower scores called the Counterforce Potentials Model. This methodology utilized existing modeling software to calculate the potential effectiveness of a weapon and then employed a eigenvalue approach to rank the value of the weapons for each force. The user had to input weapon types, numbers of weapons, and all other important information, and the output was the force ratio. To get the force ratio to change the user input different quantities of weapons. The model was used to

evaluate the Division '86 Force Structure. Lester, et. al. and Fox [27, 41], in separate analysis, found these methods lacking due to the linear nature of the modeling procedure. The firepower scores did not exhibit diminishing marginal returns. The 1500th weapon had the same potential effects as the 5th weapon. This is not a true representation of weapon effects.

The term Weapon System Effectiveness (WEI) [6, 41] was developed in 1971 by a task force of the North Atlantic Treaty Organization (NATO) Capability Study. These WEIs were quality factors used to relate the effectiveness of a specific weapon or class of weapons. For each family a set of dominate characteristics were defined. The WEI is defined as the weighted sum of these dominant characteristics. The weights are determined by subjective or Delphi techniques [6, 41, 55]. The most difficult and crucial part of the problem relating weapons within a family is to obtain values that can be summed to a unit value, referred to as weighted unit values (WUVs). Lester and Robinson [41] state that the Delphi Technique creates a wide range of inconsistent values among weapon families due to their judgmental nature.

The Quantified Judgement Method (QJM) by HERO [18, 19] was developed by Col. Trevor DuPuy. DuPuy's current book, Numbers, Predictions, and War, contain all his latest refinements [19]. Col. DuPuy's contention is that the future can be developed from the past so that predictions can be made about future

battles by updating the data in historical battles. This approach is to define a measure of outcome for actual historical battles and then adjust the weapons and the force modifiers until the actual outcome agrees with the predicted outcome in a larger proportion of the time. The outcome is measured in direction only and not to the actual degree of the real result. The QJM has no rigorous methods for data analysis and relies heavily on judgement as the name indicates [6, 41].

The Combat Effectiveness Index (CEI) was described initially by Fallon in about 1973 [6, 41]. Fallon proposed a mathematical model for combat effectiveness in terms of ordnance to achieve a kill, time to achieve a kill, logistics, dollars (cost), and response. Critiques show that the relationships for the kill and logistic kill times were both inadequate and misleading [41]. The validity of the model is scenario dependent. Bode [6] stated that the CEI illustrates the logical antimony of defining a static measure with scenario dependent factors. Thus, care must be taken to achieve either potential effects or scenario effects.

These MEIs are in the current Army models inventory. Each is still used, but as described, is both praised and criticized. There exists a lack of consistency in the factors and the overwhelming use of judgmental factors and weights contributes to their criticism. Even Galing's [28] simulation related approach reverted back to judgmental weights by using military officers to establish his scores. Reduction in the use of judgmental factors is necessary.

The Cost and Operational Effectiveness Analysis (COEA) is a procedure outlined in Tradoc Pamphlet 11-8 [76]. It is a procedure used to compare the improved effectiveness of an "item" or system to its cost. The CEOA is required for all material acquisitions in various stages of their development process [76, 80, 81, 86]. The CEOA is not a specific algorithm or model, but a general concept applied to developing models to achieve the results. O'Lone [48] addressed this problem and proposed a procedure for conducting these analysis. His proposal has yet to be approved by TRADOC and HQDA.

The use of optimization in military modeling has been noticeably absent for many years. However,in 1984, a group of professors and students [34, 43, 52] introduced the concept for the Advanced Land Air Research Model (ALARM). This model incorporated many optimization algorithms, especially in the areas of networking. Models were developed to find optimal avenues of approach, maximum flow channels, and possible choke points. The model is still being developed at the Naval Postgraduate School under the direction of Dr. Sam Parry.

Weapon System Acquisition Literature

The current army acquisition direction is specified in TRADOC Pam 11-9 [72]. Within the guise of TRADOC guidance is the requirement to provide a conceptual vision of the army modernization that spans 15 years into the future. The evolution of the Airland Battle Doctrine is the basis that guides the planning action for the next cycle leading the army

into the 21st century. TRADOC suggests the use of the Operations field manual, FM 100-5 [83], as a relevant document for the futuristic view. Army 21 plans to look further into the future. However, it is not currently published so the 15 year view is adhered to in this research.

TRADOC Pam 11-9, dated 8 July 1988 [72], contains the Army Programs Blueprint of the Battlefield. This Blueprint is the army's comprehensive, hierarchial listing of the functions and generic tasks at the tactical levels of war. This Blueprint serves as a reference system to analyze and integrate actions that the army performs in combat. The Battlefield Operating Systems (BOSs) are used to describe these generic functions. These seven BOSs are Maneuver, Fire Support, Air Defense, Command and Control, Intelligence, Mobility and Survivability, and Combat Service Support. Within these seven BOSs are generic functions that are considered in the development of component/attribute breakdown of the force multipliers.

Within the Material Acquisition Process (MAP) the term "concept" refers to any document that supports the various steps in the acquisition process [80, 81, 86]. The application of these MAP "concepts" are further addressed in both TRADOC Pamphlet 70-2 and AMC Pamphlet 70-2 [80, 81]. Both of these 70-2 series are Material Acquisition Handbooks. The Material Acquisition Handbook describes the policies, procedures, and responsibilities for initiating requirements, conducting research and development, and acquiring material items or

systems to satisfy HQDA approval requirements. The Army developed its new Army Streamlined Acquisition Process (ASAP) due to the long time required to bring material items into the force by the old method. Figure A-7 shows the comparison of the two approaches.

There are three categories of the army acquisition programs. Programs are designated into these categories based upon development risks, urgency, congressional interest, joint service involvement, and resource requirements. The three categories [67, 68, 72] are: DOD Major programs, Designated Acquisition Programs (DAP) and In-Process Review (IPR). The differences between the designations is cost. DOD major programs are usually programs which exceed $200M RDTE or $1B in procurement in FY80 dollars. The DAP are usually programs which exceeds $100M RDTE or $500M in procurement. All others are IPR programs.

Our emphasis here is merely to illustrate that the MAP is extremely complicated even with the ASAP process. The Program Managers, whose responsibility it is to nurture and bring the system from conception through fielding, have their careers at stake with the item or system. As in the case of the M1 tank, the PM is pushing improvement even prior to fielding the system so that both the system and the PM achieve their maximum effectiveness. This unbridled pushing can possibly be controlled through an application of this research's modeling and methodology.

ACQUISITION PROCESS COMPARISON

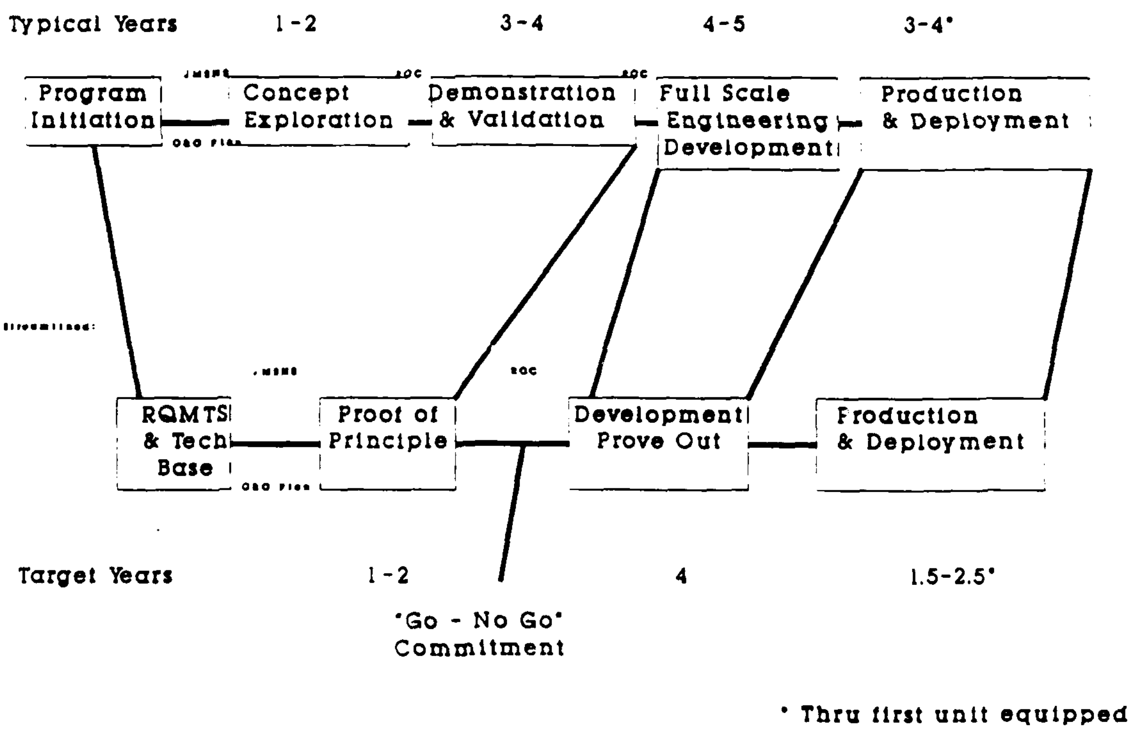

Figure A-7. Acquisition Process Comparison (See References 80 and 81)

Need for a Design Model

The problems discussed in weapon system modeling and acquisition establish a need for a model that will aid decision makers to design a weapon system. This weapon system design needs to be the most effective design that the budget allows. The effectiveness of the design is measured by the Force Multiplier value. The lack of a quantification technique for Force Multipliers is the first obstacle that a model must overcome.

A Force Multiplier is a word used to describe any factor that increases a force's effectiveness. It is almost always used in the acquisition process for any military item or system. Project Managers, Combat Developers, and other associated personnel describe their system to the highest level decision makers as "true" , "potential", or "great" force multipliers. Besides material acquisition the term force multiplier has been used to describe new training, morale factors, leadership ability, force structure, and other factors. Currently, Force Multiplier is one of the strongest "BUZZ" words without substance [6, 15, 41]. The definitions by Dupuy, Tan, and Galing [14, 15, 23, 52] attest to this lack of substance by the inability to fully develop the mathematical expression for a force multiplier. The decision makers hear that "items" are force multipliers, so other characteristics are used to describe a system. The central decision making authority has a seemingly impossible task: compare the

improved firepower of tank A, the enhancements of radio B, the capabilities of radar tracking device C, the leadership training course D, etc. There is not even a clear delineation among these systems. As previously shown, items or systems can lose their funding partially or completely. It appears as though the decision is strictly based upon two factors: the budget and the prioritization of the "items" by a panel of general officers.

This research defines quantitatively the Force Multiplier. A weapon system's component parameters are used with a set of situational inputs to calculate these Force Multiplier values. The Indicators of Force Multiplier's (INFORM) Model was developed using these calculations as a decision makers' tool. The ability to quantitatively compare "items", systems, procedures, force structures, and training, through a common method, is critically needed in the Department of Defense. The current void in the DOD modeling community will be filled through the application of this modeling approach. The INFORM Model is a specification and component selection model with the goal: maximize the force multiplier potential of the "item" in a limited resource environment. The current form of the INFORM model is the design of a main battle tank.

Decomposition of a Weapon System

Both the Force Multiplier attributes and the system components of a weapon system are decomposed for a design problem for a main battle tank. The level of decomposition is

the lowest major subsystem as defined in Chapter IV. Figures A-8 to A-13 describe this weapon system's decomposition levels and the mapping of its components into the force multiplier attributes.

Further decomposition is required for the system components. The components are described by a set of parameters. These parameters distinquish one alternative from another. These parameters are used in the model to show the impact that a component's alternative has on a system design. Figure A-9 illustrates the decomposition of a main gun armament component into its parameter set. These parameters are used to calculate the four subfunctions of the Lethality submodel (Appendix B). Each alternative (105MM, 120MM, and 120MM Energized) has different values of the prescribed parameters associated with it.

Compatibility

The compatibility matrices used in the selection of component and alternative sets for a main battle tank are illustrated in Tables A-3 to A-5 [12, 38, 60]. These matrices show that there is not a compatibility problem among the components selected to design a main battle tank.

The complete set of alternatives for each component set are listed in Figure A-14. These alternative/alternative sets were selected after examining the compatibility matrices.

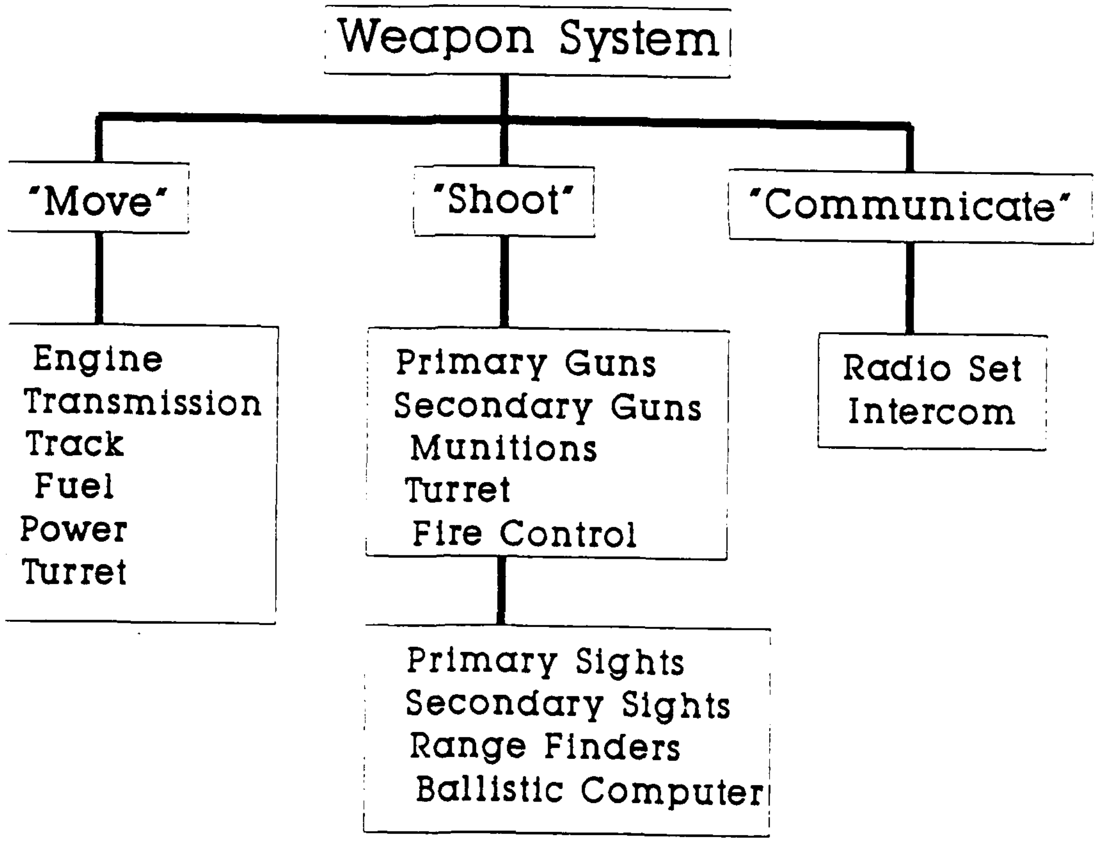

Figure A-8. Weapon System Components

SHOOT

Primary Guns
Secondary guns
Munitions
Turret

rate of fire
basic load
prob(hit)
prob(kill)
range
max. effective range
muzzle velocity
weight
armor penetration radius
time to detect
time to aim
time to fire
time to reload
projectile time
type munition
emission wavelength
reliability
availability
maintenance ratio
cost

Primary sights
Secondary sights
Range finder
Ballistic Computer
Tracking system
Turret

reliability
time to identify
time to track
time to acquire
time to traverse
max. range
azimuth range
elevation range
slew rate
tracking rate
availability
maintenance ratio
emission wavelength
cost
weight

Figure A-9. The "Shoot" Parameters

MOVE

Engine Transmission Armor body Turret	Track Suspension Shocks Armor Roadwheels	Fuel System	Power System Turret
cost reliability availability maint. ratio weight horsepower speed acceleration gross area gear ratio manual/automatic torque engine heat wavelenght engine area verticle climb ditch factor ground clearance miles per gallon	cost reliability availability maint.ratio area shoe number tracks number shocks type suspension verticle climb ditch factor track factor roadwheels ground pressure grousser factor	cost reliability availability maint. ratio type fuel capacity fuel range MPG	cost reliability availability maint. ratio voltage number of max. batteries altenator generator amps.

Figure A-10. The "Move" Parameters

COMMUNICATE

Radio set
- cost
- availability
- maintenance ratio
- grade of service
- wavelength
- power
- range
- antenna gain
- bandwidth
- effective range

Intercom
- cost
- availability
- maintenance ratio
- grade of service
- wavelength
- power

Figure A-11. The "Communicate" Parameters

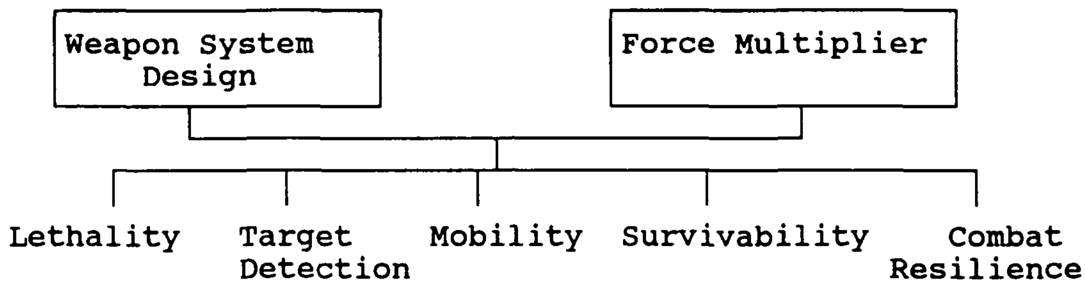

Figure A-12. Weapon System/Force Multiplier Design

FORCE MULTILPIERS

	Leth.	Target Detect.	Mobility	Survivability	Combat Resil.
"MOVE"					
Engine			X	X	X
Transmission			X	X	X
Track			X	X	X
Fuel Sys.			X	X	X
Shocks			X	X	X
Suspension			X	X	X
Armor Body			X	X	X
Power Sys.	X	X	X	X	X
Turret	X	X	X	X	X
"Shoot"					
Primary Guns	X			X	X
Second. Guns	X			X	X
Munitions	X				
Turret	X	X	X	X	X
Fire Control		X		X	X
Prim.Sights		X		X	X
Sec. Sights		X		X	X
Range finder		X		X	X
Ballistics Comp.		X		X	X
Tracking Sys.		X		X	X
"Communicate"					
Radio System	X	X		X	X
Intercom Sys.	X	X		X	X

Figure A-13. Component/Force Multiplier Mapping

Table A-3

Intrasystem Compatibility Matrix

"Culprets"	Radio Intercom	Thermal Imaging System	Ballistic Computer	Laser Range Finder
	"Victims"			
Radio-Intercom	X	C	C	C
Thermal Imaging	C	X	C	C
Ballistic Computer	C	C	X	C
Laser RF	C	C	C	X
Power Pack	C	C	C	C
Main Gun	C	C	C	C
Machine Guns	C	C	C	C
Secondary Sights	C	C	C	C
All other Equip.	C	C	C	C

Table A-4

System Compatability Matrix

"Culprets"	Engine	Transmission	Track Pads	Shocks	Power Supply
		"Victims"			
Engine	X	C	C	C	C
Transmission	C	X	C	C	C
Track	C	C	X	C	C
Shocks	C	C	C	X	C
Power Supply	C	C	C	C	C
Main Gun	C	C	C	C	C
Machine Guns	C	C	C	C	C
Other Equip.	C	C	C	C	C

Table A-5

Engine/Transmission Compatibility

	"Victims"					
	Engine			Transmission		
"Culprets"	1	2	3	1	2	3
Engine 1	X	X	X	C	X	X
Engine 2	X	X	X	X	C	X
Engine 3	X	X	X	X	X	C
Transmission 1	C	X	X	X	X	X
Transmission 2	X	C	X	X	X	X
Transmission 3	X	X	C	X	X	X
Mogas	C	C	X	C	C	X
Disiel	X	X	C	X	X	C
Power Supply	C	C	C	C	C	C
Other Equip.	C	C	C	C	C	C

Component	Alternatives
Main Gun with mounts	105 MM 120 MM 120 MM Energized
Auxiliary Gun with mounts	30 MM (M2 Gun) .50 Cal (Browning) 12.7 MM (Browning Tank)
Machine Gun with mount	7.62 MM tank coax 5.62 MM (Colt)
Target Detection Primary	Passive Sight Set (Passive Sights, Ballistic Computer, Laser Range Finder, Searchlight) Thermal Sight Set (Thermal Sights, Ballistic Computer, Laser Range Finder)
Target Detection Secondary	Night Vision Goggles and Binoculars Night Periscopes and Binoculars
Track Set	Track Pads, Dual Shocks, Dual Suspension, 12 Roadwheels Rubber Pads, Rotrary Shocks, Triple Suspension, 12 Roadwheels
Fuel Set	503 Gallon tank and pump, Disiel 508 Gallon tank and pump, Mogas
Power Set	Four 12 volt, 28 DC, 100 Amp/hr, 220 Amps Six 12 volt, 24 DC, 300 Amps/hrs, 650 Amps, Solid State
Drive Set	AGT-1500C Set AGT-2000C Set
Communications (Radio Set)	AN/GRC-64 Series AN/VRC-12 Series SINCGARS Series
Communications (Intercom)	AN/VIC-1 Series Improved Intercom Series

Figure A-14. Tank Alternative/Component Sets

Scenario

A typical European Scenario is chosen as the basis for the weapon system design problem example of a main battle tank. Specifically the following scenario related assumptions are made:

1. The nominal range in the theater is 1000 meters.
2. A target rich environment is found.
3. The T-72 Soviet main battle tank is the main enemy.
4. The area of operations is a Corps sector (160000 sqm).
5. Friendly force is a battalion of main battle tanks (54).
6. Nominal observer-target rate is 25 kph.
7. German autobahn road friction is .07.
8. Both taget and fires are stationary (SS mode).
9. Posture code is open.
10. Engagement type is flank.
11. Alpha value of the Rayleigh Distribution for Europe is 1000 (see Appendix B).

Other scenario entries are made as best estimates. These entries are found in Appendix D.

Model and Design Results

The user and component data shown in Appendix D were used to execute a main battle tank design problem. The user data is representative of the type situational data commonly found in the European Theater. The main battle tank under design has eleven system components in the model. The results of a

complete main battle tank design problem are listed below.

The final design solution selected is:

- 120 MM main gun,
- 12.7 MM auxiliary gun,
- 7.62 MM tank machine gun,
- Thermal Primary Sight Group,
- Secondary Night Vision & Periscopes,
- Rubber Track Set,
- Larger Capacity Fuel tank,
- Highest amp power set,
- 1500 HP engine set,
- SINCGARS radio and
- Improved Intercom set.

This design solution for a main battle tank is identical to the current Phase II M1 battle tank [91]. The model provides a list of selected components for a main battle tank. When these components are properly assembled, forming a main battle tank, they achieve the highest Force Multiplier value within a limited resource environment. This version of an example main battle tank is within the prescribed budget. The Force Multiplier value for this main battle tank is 1.3643. Under the user's tactical conditions set in this model, this main battle tank is 36.43% more effective than the M60 series tank.

Glossary of Terms

ADATS - Army Development and Acquision of Threat Simulation.

ASAP - Army Streamlined Acquisition Process used to reduce the number of years to acquire a system.

ASAS - All Source Analysis System for intelligence gathering.

BDP - Battlefield Development Plan.

BOIP - Bais Issue Plan for systems.

BOS - Base Operating System.

CAL. - Caliber of a weapon.

CC - Command and Control.

C3I - Command, Control, Computers, and Information.

CDers - Combat Development Centers at each branch school responsible for material, doctrine, force structure, and tactical solutions to problems.

CEI - Combat Effective Index.

CG - Commanding General.

COEA - Cost and Operational Effectiveness Analysis. A study required prior to a system's acquisition.

DAP - Designated Acquisition Programs. Systems watched closely by the Secretary of Defense.

DCD - Directorate of Combat Developments.

DOD - Department of Defense.

DOTD - Directorate of Training Development located at branch schools.

FAX - Facsimile system or device.

FM/FC - Field Manuals or Field Circulars that provide information and quidance to soldiers in the field.

Force Multiplier - Anything that changes the combat effectiveness of an "item".

FY - Fiscal year.

HQDA - Headquarters, Department of the Army located in Washington, D.C.

INFORM - Indicators of Force Multipliers Model written to design a main battle tank weapon system.

LHX - Light Helicopter. A new helicopter system being designed for the future.

MAA - Mission Area Analysis. An internal study performed every 1-2 years to address mission deficiencies.

MADP - Mission Area Development Plan. A classified analysis of the MAA and the BDP.

MAP - Material Acquisition Plan.

MEI - Measure of Effectiveness Index.

METT-T - An acronym used to decribe critical combat factors of mission, enemy, terrain, troops, and time.

MILES - Multiple integrated laser equipment system. A surrogate for weapon system effects for combat training.

M1 - The U.S. main battle tank (Abrams tank).

M1A2 - Phase II of the M1 main battle tank.

M60 - Older version of the U.S. main battle tank.

MM - Millimeter.

MSE - Mobile Suscriber Equipment. A new communication systems used for the division and below.

NTC - National Training Center based in Fort Irwin, California used to train infantry and armor battalions.

OCOCA - An acronym used to describe critical defensive factors of cover, obstacles, concealment, and avenues of approach.

OO Plan - Operational and Organizational Plan for new systems.

Ph - Probability of hit.

Pk - Probibility of kill.

PM - Program Manager or the director for new systems development.

Pssk - Probability of single shot kill.

QJM - Quantified Judgement Method developed by HERO for combat modeling.

Qssk - Probability of single shot kill for the enemy.

QQPRI - Qualitative and Quantitative Personnel Requirements Information.

R&D - Research and development.

RDTE - Research, development, testing, and evaluation.

ROC - Requirements Operational Capability specification document.

SINCGARS - Single channel ground and airborne radio system.

T-72 - Soviet main battle tank.

TOE - Table of Organization and Equipment.

TRADOC - Training and Doctrine Command located at Fort Monroe, Virginia.

TRM - TRADOC resource management.

WEI - Weapon Effectiveness Index.

WUV - Weighted to unit value.

Appendix B

Submodels and Model Formulation

A weapon system is defined as an instrument of combat used to destroy, injure, or threaten an enemy [17]. By extension, any device, method, or circumstance that can be used to destroy, injure, or threaten an enemy is also a weapon system. Thus, a weapon system consists of those components required for its operation. These components of the weapon system are essential elements of its combat effectiveness.

The effectiveness of a weapon system, in this research, is determined by the Force Multiplier value. Since this value covers many diverse activities on a battlefield, it is decomposed into manageable submodels. These five submodels map identically into the five design aspects of a weapon system for DOD.

A model is built by joining each of the submodels, desired to be active, in a model formulation. Prior to listing this general model formulation, it is essential to discuss the mathematical substructures of these five submodels.

These five submodels are: Lethality, Target Detection, Mobility, Survivability, and Combat Resilience. The consequences of large-scale production of weapon systems and ammunition leads to analytical investigations to find new principles and exploit them in the production of new and

better weapon systems. These five aspects and the mathematical functions, that are included within them, represent new principles to design better weapon systems. Each is discussed within this Appendix as they are used in the INFORM model.

Lethality

The lethality of a weapon system measures the ability of a weapon system to fire on an enemy and produce results that are favorable to this weapon system in a combat situation. Favorable results range from killing an enemy to preventing an enemy from performing its/their mission. Thus, killing an enemy is only part of the total lethality submodel.

The Lethality submodel consists of four subfunctions:

1. Effective Rate of Fire,
2. Mission Effectiveness,
3. Obscurity Effectiveness and
4. Kill Effectiveness.

1. Effective Rate of Fire (ERF). The ERF measures the amount of potential munitions a weapon can effectively place on a target (or targets) on a battlefield. The parameters of an armament component for a weapon system that effect this function are the basic load and the rate of fire of the "gun". The user's tactical input, the engagement length, represents a time parameter used in this function.

In some systems, the amount of steel placed encasing a target becomes a factor of system performance and has an impact on the mission. The amount of steel encasement is a function of the basic load and the rate of fire [5, 19, 87, 88, 94]. The ERF is calculated by:

$$ERF = \frac{\text{Basic Load}}{\text{Rate of Fire x Engagement Length}} \qquad (B.1)$$

where

Basic Load = the amount of munitions carried,

Rate of Fire = the number of rounds per minute,

Engagement Length = time in minutes.

2. Mission Effectiveness (ME). The mission effectiveness is concerned with the impact that an armament component has on the overall system's mission, in relationship to other systems on a battlefield. The system's parameter used is the probability of single shot kill (Pssk) of an armament component and the tactical inputs are the enemy kill probability (Qssk) and the number of systems on a battlefield. The ERF function is used in this calculation since the amount of steel on the target impacts upon mission accomplishment. The ME [5, 19] is calculated by

$$ME = NS \times (1 - (1 - Pssk)(1 - Qssk)^{ERF}) \qquad (B.2)$$

where

NS = number of systems,

Pssk = friendly system's probability of single shot kill,

Qssk = enemy system's probability of single shot kill,

ERF = engagement rate function.

3. Obscurity Effectiveness Function (OEF). This function is concerned with the impact that tactical factors have on the performance of weapon components. Tactical inputs of range, target density, target posture, observer-target rate, and degradation and obscurity factors (the effects of weather, terrain, smoke, etc.) are used with the time parameters of a system's components to acquire, fire, and reload. A weapon system must be able to function effectively in an environment that is relatively uncontrollable. These uncontrollable factors are smoke, weather, and terrain and they are used to calculate an OE constant (see equation B.3) to measure these factors within the model. The OEF (see equation B.4) [5, 19] is calculated with the OE constant and the system's time parameters.

$$OE = \text{range} \times \text{density} \times \text{observer-target rate} \times \text{posture} \times \text{degradation factors} \quad \text{and} \tag{B.3}$$

$$OEF = \frac{OE}{t_a + t_r + t_f} \tag{B.4}$$

where

t_a = time to acquire,

t_r = time to reload,

t_f = time to fire.

4. Kill Effectiveness (KE). The kill effectiveness

submodel measures the potential kill effectiveness of an armament component against enemy targets on a battlefield. Armament component parameters include basic load, Pssk, and the times to/for detect, fire, projectile flight, and reload. The communication's component parameter of Grade of Service (GOS) acts as a degradation factor for combat information transfer [37, 49]. The tactical inputs are range, engagement time, and an alpha value (α) for the engagement probability function. This mathematical relationship is established using an established kill potential's function [94] as a guide. The major modification is the inclusion of the degradation factor by the communications equipment.

$$KE = \frac{Etime \times bl \times Pssk \times P(engagement) \times GOS}{(t_a + t_r + t_f)} \tag{B.5}$$

where

Etime = engagement time in seconds,

bl = basic load,

Pssk = probability of single shot kill at enemy j,

P(eng.) = probability of engagement at range r,

GOS = Grade of Service,

t_a = time to acquire,

t_r = time to reload,

t_f = time to fire.

The Pssk and the probability of engagement can be

functions of range. The Pssk, for various ranges and postures, may be either a constant or a variable depending on the armament component. In this research, the Pssk is considered a constant. The probability of engagement depends solely on the tactical inputs of range and the alpha value. A Rayleigh distribution is used to describe the probability of engagement at a given range. Alpha (α) values are chosen from 500, 1000, or 1500. An α value of 1000 is reasonable for open terrain in Central Europe, a smaller value is appropriate for mountainous or urban terrain, and a larger value is appropriate for desert warfare [27, 94]. Smaller α values can be used to examine the effects of night or bad weather as those factors alter the expected engagement ranges.

$$\text{Prob(Engagement)} = 1 - \text{EXP}(-.5 \times (R/\alpha)^2) \qquad \text{(B.6)}$$

where

R = range,

α = nominal value (500, 1000, or 1500).

5. Lethality. The Lethality submodel is defined as the sum of these four subfunctions. Each subfunction is given an equal weighting in this relationship. This summation is then scaled by the lethality summation of a baseline system. The new result is a Force Multiplier value for lethality of a component.

$$\text{Lethality} = \text{ERF} + \text{ME} + \text{OEF} + \text{KE} \text{ and} \qquad \text{(B.7)}$$

$$\text{FM(lethality)} = \text{Lethality(new)}/\text{Lethality(Baseline)}. \qquad \text{(B.8)}$$

Target Detection

Target detection on a battlefield consists of finding the potential targets. Weapon systems have components whose sole purpose is to enable a weapon system to detect and identify enemy targets on a battlefield. (The enemy in this research is the Soviet T-72 main battle tank with footsoldiers.)

The Target Detection submodel [35, 87, 88] consists of one major function, Detection, and two functional constants: a Detection constant and an Obscure Detection constant. The purpose of this submodel is to measure the effectiveness of the primary and secondary detection components of a weapon system. The detection function uses the sum of the times required by the components to sense, track, identify, acquire, and orient the gun on a known potential target. The assumed reliability of the components is an important parameter used in the calculations. The tactical input values of human reliability and the two constants, formed from the other values, are part of the detection function [5, 87, 88].

$$\text{Detcons} = \frac{2 \times \text{range} \times \text{Obs-tgt rate} \times \text{Search length} \times \text{density}}{\text{width of search path} \times \text{area}} \tag{B.7}$$

where

range = distance in meters,

obs-tgt rate = relative speed between systems,

search leng. = time to observe in seconds,

density = average target density on battlefield,

width path = distance in meters,

area = coverage area in meters.

Doecons = OE x enemy posture x human factors reliability (B.8)

where

OE = defined as before Obscured constant,

enemy posture = open or defilade,

hf reliability = the human factor to make an ID mistake.

$$TDF = \frac{\text{Detcons x Doecons x probability of success}}{(t_s + t_{tr} + t_{id} + t_a + t_{lg})} \qquad (B.9)$$

where

t_s = time to sense a target,

t_{tr} = time to track a target,

t_{id} = time to identify a target,

t_a = time to acquire a target,

t_{lg} = time to lay the gun on a target.

The target detection function is transfo:med into a Force Multiplier value for target detection by dividing by a target detection value for a baseline system. The Force Multiplier values is expressed by

FM(TD) = TDF(new)/TDF(Baseline), (B.10)

Mobility

The concepts of mobility, agility, and maneuverability have defied definition and quantification for many years [87, 88]. It is essential that these measures be included in any evaluation process for weapon systems. Therefore, models to provide these quantifications are established using as many guides as possible [5, 19, 87, 88].

Mobility is defined [86, 87] as the capability of military forces that permits them to move from place to place while retaining the ability to fulfill their mission. This definition is transformed to cover the capability of a weapon system's component to move from place to place while retaining its ability to perform its mission. Maneuver is the tactical employment of mobility and agility is the measure of a weapon system to move quickly and easily on a battlefield. Some of these measures and potential models for these measures were found in handbooks and articles [5, 41, 87, 88].

The Mobility submodel uses all the defined attributes of agility, maneuver, and mobility. These attributes are used to calculate functions that describe a system's mobility on a battlefield. The following subfunctions are defined for this submodel:

1. ET - Effective Tractice Effort,
2. TVE- Tractive Vehicle Effort,
3. AGI- Agility (Inverse of VCI)

4. Mob- Mobility of body,

5. Moa- Mobility of armament and

6. Mod- Mobility of detection.

1. ET. Effective Tractive Effort measures amount of force delievered by the engine and transmission. The maximum value of the tractive effort is the weight of the vehicle. The tractive effort concept is fully developed as part of the MOBTANK model [87] and only applicable parts are used in this rersearch.

$$ET = \text{horsepower}/\text{vehicle speed} \quad . \tag{B.11}$$

2. TVE. The tractive vehicle effort of the weapon system is a function of the ET and the factor for engine inertia required for acceleration. The factor of inertia is proportional to the horsepower and the square of the gear ratio [87]. A tactical input value for the coefficient of friction for the road surface is used in this model. The parameters of gear ratio, horsepower, and speed are used. This expression comes from the MOBTANK model [87].

$$TVE = \frac{\text{gear ratio}^2 \times \text{horsepower}}{\text{speed} \times \text{coef. of friction}} \quad . \tag{B.12}$$

3. AGI. The Vehicle Cone Index (VCI) inverse is used to describe the agility of the system. The VCI measures the ability of a system to move around on the battlefield [32]. A smaller VCI is better than a larger value. Thus, the

effective measure of agility (AGI) is the inverse of the VCI. All the factors are functions of the parameters of the mobility components. These include: contact pressure factor, weight factors, track factors, grouser factors, roadwheel factors, clearance factors, engine factors, and transmission factors.

$$VCI=25.2 + .454 \times \left[\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{track factor} \times \text{grouser factor}} + \text{roadwheel factor} - \text{clearance factor} \right] \times \text{engine factor} \times \text{transmission factor} \qquad (B.12)$$

where

$$\text{contact pressure factor} = \frac{\text{gross weight}}{\text{area of ground contact}} ,$$

track factor = trackwidth/100 ,

$$\text{roadwheel factor} = \frac{\text{gross weight}/10}{\text{number of roadwheels} \times \text{area of track shoe}} ,$$

clearance factor = clearance/10 ,

transmission factor (manual) = 1.05 ,

weight factor = weight(pounds)/60000 ,

engine factor = horsepower/ton/13.8 ,

grouser factor = grouser length/1.5.

As stated, the AGI is the inverse of the VCI.

$$AGI = 1/VCI \quad . \qquad (B.13)$$

4. Mobility of body. This function measures the effect

of speed and cruising range on the maneuverability of the system on a battlefield [19, 87, 88].

$$Mob = .15 \times \sqrt{(speed)} + .08 \times \sqrt{(cruise\ range)}\ . \quad (B.14)$$

5. Mobility of armament. This function measures the ability of the armament components to maneuver on a battlefield. It is a function of the traverse rate and the Mob [19, 87, 88].

$$Moa = Mob \times traverse\ rate \quad (B.15)$$

where

traverse rate = time to traverse the through area.

6. Mobility of detection. This function measures the ability of the detection equipment to maneuver on a battlefield. It is a function of the tracking rate and the Mob [19, 87, 88].

$$Mod = Mob \times tracking\ rate \quad (B.16)$$

where

tracking rate = sum of times to track through the area.

7. Mobility Function. The Mobility function is defined as the sum of the six subfunctions:

$$MOB = ET + TVE + AGI + Mob + Moa + Mod\ . \quad (B.17)$$

The Force Multiplier value for a mobility component is defined as the MOB of the new component divided by the MOB of a baseline component.

$$FM(MOB) = MOB(new)/MOB(Baseline)\ . \quad (B.18)$$

Survivability

Survivability considers the system's ability to survive on a combat battlefield. Surviving on a battlefield means the ability to avoid or withstand the effects of enemy action and still continue the mission [88]. The major subfunctions included in this model are:

1. Hitability,
2. Detectability,
3. Vulnerability,
4. Heat Index and
5. Signal/Noise ratio.

Both hitability and vulnerability deal with a system's ability to withstand the effects of the enemy and still perform its intended mission. The remaining subfunctions are concerned with avoiding the effects of an enemy, by not being seen, heard, or sensed.

1. Hitability. This function is concerned with the exposed target area of the component or system. Several tactical inputs, posture and observer-target rate, are included in this model. A hit constant is calculated using the tactical parameters of the model that do not change with the alternative selections. A Hitability function [88] is approximated by

Hit constant(HC) = posture factor x ot rate and

$$\text{Hitability} = \frac{\text{HC} \times (\text{exposed target area})^{1.5}}{\text{Weight}} \qquad \text{(B.19)}$$

where

HC = hit constant,

ot rate = the observer to target rate.

2. Detectability. The probability of being detected by an enemy is defined by an exponential distribution [5, 88]:

$$P(D) = 1 - EXP\left[\frac{-(\text{ot rate} \times \text{density} \times \text{Pssk})}{\text{width of search path} \times \text{weight}} \right] \quad . \text{(B.20)}$$

3. Vulnerability. Vulnerability applies a kill or be killed concept to a system. A component's reliability and its Pssk reflect the component's contribution. Tactical inputs include "probability of line of sight" and a "survive constant". This function is modified, from the literature, by combining two functions to define vulnerability effectiveness [5, 88].

$$\text{Survive (SC)} = 1-(1-\text{average density})^{\text{number of glimpses}} ,$$

$$\text{Vul} = 1-(\text{Pssk} \times \text{Qssk} \times P(\text{LOS}) \times \text{Reliability} \times \text{SC} \quad \text{(B.21)}$$

where

density = average target density on a battlefield,

glimpses = number of looks made in a target direction,

Pssk = single shot kill probability (Friendly),

Qssk = single shot kill probability (Enemy),

P(LOS) = probability of line of sight,

SC = survive constant.

4. Heat Index. This function measures the effective heat given off by a component [88]. The average temperature

reached by the component is the value used in the model. The heat leads to being detected by enemy sensors or being killed by enemy heat seeking munitions.

$$\text{Heat} = \frac{\text{Width of search path}}{\text{wavelength}^2 \times 5.7 \times 10^{-12} \times \text{temp}^4} \qquad \text{(B.22)}$$

where

temp = temperature of heat emissions in Kelvin,

wavelength = emissions wavelength in cm or m,

5.7×10^{-12} = Stefan-Boltzman constant.

5. Modified Signal to Noise Ratio. This measures the effectiveness of not being detectable by electromagnetic devices. It is primarily used with communication devices of the weapon system. This subfunction is defined as [48, 88]:

$$\text{SN} = \frac{\text{GOS} \times \text{Bandwidth} \times \text{Power output}}{\text{Wavelength} \times \text{target exposed area}} \quad . \qquad \text{(B.23)}$$

6. Survivability. Survivability is defined as the sum of these five functions:

$$\text{SURV} = \text{Hit} + \text{Detect} + \text{Vul} + \text{heat} + \text{SN} \quad . \qquad \text{(B.24)}$$

The Force Multiplier value for survivability is the ratio of the new survivability value of a system to the survivability value of a baseline system.

$$\text{FM(Surv)} = \text{SURV(new system)}/\text{SURV(Baseline system)}. \qquad \text{(B.25)}$$

Combat Resilience

Combat Resilience refers to a system's ability to operate continuously on a battlefield [57, 58, 59]. The officers that invented this term considered many factors that effect battlefield longevity. One of these factors, the Battlefield Damage Assessment and Repair Model [47], is not included in this research because it is unavailable. The factors, included as subfunctions for this model, are a system's availability and a system's maintenance ratio [42, 87, 88]. Each system is decomposed and a system's availability and maintenance ratios are treated as independent variables.

$$\text{CR} = \text{Availability} + \text{Maintenance ratio} \qquad \text{(B.26)}$$

where

$$\text{Availability} = \frac{\text{operating time}}{\text{operating time} + \text{down time}} \quad ,$$

$$\text{Maintenance Ratio} = \frac{\text{time to repair}}{\text{down time}} \quad .$$

The CR Force Multiplier value is defined as the ratio of the CR function of a new system to a baseline system.

$$\text{FM(CR)} = \text{CR(new system)/CR(baseline system)} \quad . \qquad \text{(B.27)}$$

These five submodels comprise the total criterion function model and its formulation. As more submodels are added, the larger the formulation of the design model of a weapon system becomes. The model formulation is dependent upon the number of submodels that are actived. A

representative example of the formulation is illustrated, with all previously defined submodels active, in the figure that follows. The criterion function of Figure B-1 is the sum of the Force Multiplier submodels in each of the five aspects: Lethality, Target Detection, Mobility, Survivability, and Combat Resilience. The constraints of the formulation are developed from the user's specification for the performance of the components and the cost/budget resource.

Model Formulation

Criterion Function:

$$\sum_{i=1}^{I_A} \sum_{a=1}^{A} FM(L)_{ia} X_{ia} + \sum_{i=1}^{I_D} \sum_{d=1}^{D} FM(TD)_{id} X_{id} + \sum_{i=1}^{I_M} \sum_{m=1}^{M} FM(MOB)_{im} X_{im} +$$

$$\sum_{i=1}^{I_k} \sum_{k=1}^{K} [FM(Surv)_{ik} + FM(CR)_{ik}] X_{ik}$$

Subject to:

Resource in dollars:

$$\sum_{i=1}^{I_k} \sum_{k=1}^{K} C_{ik} X_{ik} \le B$$

Power consumption in amps:

$$\sum_{i=1}^{I_k} \sum_{k=1}^{K} PC_{ik} X_{ik} \le P$$

Every component appears only once:

$$\sum_{i=1}^{I_k} X_{ik} = 1 \text{ for } k=1,2,3,...,K$$

Muzzle velocity in meters per second:

$$\sum_{i=1}^{I_a} MV_i X_{ia} \ge MV \text{ for } a=1,2,...,A$$

Basic load specification in rounds:

$$\sum_{i=1}^{I_a} BL_i X_{ia} \ge BL \text{ for } a=1,2,...,A$$

Armament range in meters:

$$\sum_{i=1}^{I_a} MR_i X_{ia} \ge MER \text{ for } a=1,2,...,A$$

Kill potential against target type j specification:

$$\sum_{i=1}^{I_a} PK_i X_{ia} \ge TGT_j \text{ for } a=1,2,...,A \text{ and } j=1,2,...,J$$

Detection range specification in meters:

$$\sum_{i=1}^{I_d} RM_i X_{id} \ge RM \text{ for } d=1,2,...,D$$

Horsepower specification:

$$\sum_{i=1}^{I_m} HP_i X_{ik} \ge HP \text{ for } k=9 \text{ (Drive set)}$$

Gear ratio specification for the transmission:

$$\sum_{i=1}^{I_m} GR_i X_{ik} \ge GR \text{ for } k=9 \text{ (Drive set)}$$

Miles per gallon specification:

$$\sum_{i=1}^{I_m} MPG_i \, X_{ik} \geq MPG \text{ for } k=9 \text{ (Drive set)}$$

Speed specification:

$$\sum_{i=1}^{I_m} MaxSpeed_i \, X_{ik} \geq Maxspeed \text{ for } k=9 \text{ (Drive set)}$$

Cruising range specification in meters:

$$\sum_{i=1}^{I_m} CR_i \, X_{ik} \geq CR \text{ for } k=9 \text{ (Drive set)}$$

Emissions signal (Heat temp in degrees Kelvin)

$$\sum_{i=1}^{I_m} Heat_i \, X_{ik} \leq Heat_{min} \text{ for } k=9 \text{ (Drive set)}$$

Minimum transmission power in watts specificiation:

$$\sum_{i=1}^{I_c} PW_i \, X_{ik} \leq PW \text{ for } k=9,10 \text{ (Drive set and Commnications)}$$

Specification for torque delievery:

$$\sum_{i=1}^{I_m} T_i \, X_{ik} \geq T \text{ for } k=9 \text{ (Drive set)}$$

Specification for armor protection thickness:

$$\sum_{i=1}^{I_m} A_i \, X_{ik} \geq A \text{ for } k=9 \text{ (Drive set)}$$

Communications range specification in kilometers:

$$\sum_{i=1}^{I_c} CD_i \, X_{ik} \geq CD \text{ for } k=10 \text{ (Communications)}$$

Minimum common repair parts specification:

$$\sum_{i=1}^{I_k} RP_i \, X_{ik} \geq 1 \text{ for all } k=1,2,\ldots,K$$

Verticle climb specification in meters:

$$\sum_{i=1}^{I_m} VC_i \, X_{ik} \geq VC \text{ for } k=6,7,8,9$$

Ditch traverse specification in meters:

$$\sum_{i=1}^{I_m} DW_i \, X_{ik} \geq DW \text{ for } k=6,7,8,9$$

Acceleration specification:

$$\sum_{i=1}^{I_m} AC_i \, X_{ik} \geq AC \text{ for } k=9 \text{ (Drive set)}$$

Minimum Grade of Service specification for communications:

$$\sum_{i=1}^{I_c} GOS_i \, X_{ik} \geq GOS \text{ for } k=10,11$$

Appendix C

Program Listing and Sample Outputs

```
c*******************************************************
c     THE INDICATORS of FORCE MULTIPLIERS MODEL
c                    INFORM
c*********************************************************
c The purpose of the program is to provide a decision aide
c to  the designer of weapon systems. This program's
c solution  contains the alternatives of the system
c components selected to maximize the Force Multiplier of
c the system.
c*********************************************************
C********************** VARIABLE DEFINITIONS ***************
c
c User - the data elements from 1-60 supplied by the user.
c        They include tactical elements and specifications.
c Comp - this is a matrix of all the alternatives and
c        components of the system. It's maximum size is 30
        rows. Seventy
c       (70) columns are used for the parameters of the
c        components.
c X    - This matrix contains the boolean expression for the
c        alternative value in each component of the system.
c FMS  - Holds the upper value forthe Force Multiplier
c l    - An array listing the number of alternatives per
c        component. - An array listing the row number of the
c        solution array.
c mm   - Hold the original solution array.
c cd   - The array of Cost Differences.
c        also Delcost and diffcost
c fmd  - The array of Force Multiplier Differences.
c        also DelFM and DifFM
c M60**- The scaling factors for all the components. There
C        are eleven scaling factors.
c Oe   - The amount Underbudget to be spent in Inclusion.
c Ob   - The amount Overbudget to be removed in Exclusion.
c oo   - The alternatives Excluded.
c pp   - The alternatives included.
c kill - The Lethality Force Multiplier per alternative.
c TD   - The Target Detection Force Multiplier per
c        alternative.
c MO   - The Mobility Force Multiplier per alternative
c SURV - The Survival Force Multiplier per alternative.
c CR   - The Combat Resilience Force Multiplier per
c        alternative.
c
c ******************* FLAGS **************************
c Flags indicate if a submodel is active (1) or inactive
c     (0).
```

```
c Lfalg- Lethality submodel
c TDflag- Target Detection submodel
c MOflag- Mobility submodel
c Survflag- Survivability submodel
c CRflag- Combat Resilience submodel
c***********************************************************
c************************************************************

c************************************************************

c ************** DECLARED VARIABLES ************************

c**************** Dimension and Common Variables ******
c *** NOTE- A maximum use of COMMON was exercised.
c************************************************************

      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totcost,FML,FMTD,FMMOB,
     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,
    +mm,mmm,Flag,numc,oo,pp,mnop
      write(*,*) 'Welcome to the INFORM Model.'
c************************************************************

c Insure that the User/Analyst knows their responsibilities
c of
c data input required for the model prior to running the
c model.
c************************************************************
c************************************************************
c USER INTERFACE
c************************************************************
c
c Interactive data or data file ?
      Flag=0
       write(*,*)'Please indicate by entering a 1 for
          activate'
       write(*,*)'or a 0 for non-activation for each of the'

       write(*,*)'submodels in the following order:'
       write(*,*)'Lethality, Target Detection, Mobility,'
       write(*,*)'Survivability, and Combat Resilience.'
```

```
       read(*,*) Lflag,Tdflag,Mobflag,Survflag,Crflag
c*************************************************************
      Write(*,*)'Enter the required data interactively (1)
              or'
      Write(*,*)'from a data file (2)'
      read(*,*) mdatresp
      if(mdatresp.eq.2) then
       open (unit=11,file='analyst.dat',status='old')
       read(11,*) (user(i), i=1,58)
      else
c ** Interactive prompts to access user data.
c *****************
      write(*,*)'Please enter the following data in short
             burts.'
      write(*,*)'Enter the DOD budget for this system'
      read(*,*) user(1)
      write(*,*)'Enter the enemys probability of kill and
             hit.'
      read(*,*) user(2),user(3)
      write(*,*)'Enter the search width (meters) .'
      read(*,*) user(4)
      write(*,*)'Enter the area of operations (Square
         meters).'
      read(*,*) user(5)
      write(*,*)'Engagement length in seconds'
      read(*,*) user(6)
      write(*,*)'Reliability in Mission accomplishment
          (0<R<1).'
      read(*,*) user(7)
      write(*,*)'Number of weapon systems in this analysis'
      read(*,*) user(8)
      write(*,*)'Enter the degradation and obscurity
        factors'
      read(*,*) user(9),user(10)
      write(*,*)'Enter the observer-target rate & target
            density'
        read(*,*) user(11),user(12)
      write(*,*)'Range in meters'
      read(*,*) user(13)
      write(*,*)'Enter the detection sweep angle (degrees)'
      read(*,*) user(14)
      write(*,*)'Enter alpha,Velocity-TGt code'
      write(*,*)'SS=1,MM=2,SM=3,MS=4'
c S is stationary and M is motion ******************
      read(*,*) user(15),user(16)
      write(*,*)'Human reliability factor'
      read(*,*) user(17)
      write(*,*)'Enter Coefficient of Friction for road
          type'
      read(*,*) user(18)
      write(*,*)'Number of glimpses in a search'
      read(*,*) user(19)
```

```
      write(*,*)'Probability that Line of Sight exists in
           area'
      write(*,*)' 0<P<1'
      read(*,*) user(20)
      write(*,*)'Enter the posture and engagement codes'
      write(*,*) 'Posture - Open(0),Defalade(1)'
      write(*,*) 'Engagement-Flank(0),Head(1)'
      read(*,*) user(21),user(22)
      write(*,*)'Enter total time length and operating time
              in'
      write(*,*) 'hours'
      read(*,*) user(23),user(24)
      write(*,*)'Enter priority of targets code'
      write(*,*) 'enemy tank first(1), other first(0)'
      read(*,*) user(25)
      write(*,*)'Enter search length in seconds'
      read(*,*) user(26)
c****************** Specifications ***************
c *************************************************
      write(*,*)'Enter minimum muzzle velocities for Main
           gun, '
      write(*,*)'auxilary gun, and machine gun'
      read(*,*) user(27),user(28),user(29)
      write(*,*)'Enter the minimum basic loads for the 3
           guns'
          read(*,*) user(30),user(31),user(32)
      write(*,*)'Enter maximum power consumption by main
          gun'
      read(*,*) user(33)
      write(*,*)'Enter two types target to be killed'
      read(*,*) user(34),user(35)
      write(*,*)'Enter minimum maximum effective ranges of
              the 3'
       write(*,*) 'guns.'
      read(*,*) user(36),user(37),user(38)
      write(*,*)'Enter maximum detectionpower
      consumption(amps)'
       read(*,*) user(39)
      write(*,*)'Enter the minimum accepatble maximum ranges
               for'
      write(*,*)'Range finders and sights.'
      read(*,*) user(40),user(41)
      write(*,*)'Enter the minimum acceptable of the
        following:'
       write(*,*)'Horsepower, gear ratio, MPG,Cruise range ,
         write(*,*)'and Speed'
      read(*,*) user(42),user(43),user(44),user(45),user(46)

      write(*,*)'Enter Mobility power consumption (amps)'
      read(*,*) user(47)
      write(*,*)'Enter track replacement time
       (minumum-seconds)'
```

```
      read(*,*) user(48)
      write(*,*)'Enter minimum power available '
      read(*,*) user(49)
      write(*,*)'Enter maximum heat give off of engine'
      read(*,*) user(50)
      write(*,*) 'Enter  our armor thickness'
      read(*,*) user(51)
      write(*,*)'Enter communications distance requirement'
      read(*,*) user(52)
      write(*,*)'Enter minimum commonality parts'
      read(*,*) user(53)
      write(*,*) 'Enter main gun munition armor penetration'

      read(*,*) user(54)
      write(*,*)'Enter the vertical climb (meters)'
      read(*,*) user(55)
      write(*,*)'Enter the fording depth or obsticle
        clearance'
      read(*,*) user(56)
      write(*,*)'Enter the acceleration requirement'
      read(*,*) user(57)
      write(*,*)'Enter the minimum GOS and power output
             Commo'
       read(*,*) user(58),user(59)
c ** END    Question    Prompts ****
      endif
C *** CALCULATE COMMON CONSTANTS ONCE **********************

c************************************************************

c List of constants controlled by Tactical inputs are:
c************************************************************

c oecons- The obsurity constant.
c probeng- The probability of an engagement.
c detcons-The Detection constant.
c doecons-The obscurity constant in detection.
c survcons- The vulnerability to enemy capabilities
  constant.
c hitcons - The hitability by enemy constant.
c edectcons-The detectability of a component constant.
c************************************************************
c
       oecons=(user(9)*user(10)*user(8)*user(12)*user(5))/
      +(user(13))
       probeng=(1.-(exp(-.5*((user(13)/user(15))**2))))
      write(*,*)'Prob of engagement is ',probeng

detcons=2.0*user(13)*user(11)*user(26)*user(54)/(user(5)*
     +user(13))
c ***(note)************ Human Factors is user 55
c ********************************************
```

```
      doecons=oecons*user(21)*user(55)
      survcons=(1.0-((1.0-(user(21)/user(4)))**user(19)))
      hitcons=user(21)*user(11)
      edectcons=1.0/(1984.4017*(user(13)**4)*(1.38*10.**
    +(-23))*(290.))

write(*,*)'***************CONSTANTS*****************'
      write(*,*)'lethal detection constant is ',detcons
      write(*,*)'target detect is ',doecons
      write(*,*)'Obscured constant is ',oecons
      write(*,*)'survive constant is ',survcons
      write(*,*)'hitability constant is ',hitcons
      write(*,*)'Signal to Noise ratio is ',edectcons

write(*,*)'********************************************'
c***************note***************************************
***** c Let's call the data User(NN)- where each item in
position NN
c has a specific purpose in the model.
c
***********************************************************
*** C
c Output file opened as Tank.out !
      open(unit=73,file='tank.out',status='new')
c**********************************************************
c *
c********** SCALING FACTORS *****************************
c Scaling factors in this program are from the baseline
c system.
c The baseline system is the M60 series tank.
c*********************************************************

M60L(1)=(.15*user(6)/60.)+(user(8)*((.25*(1.-user(2)))**
   +(.15*user(6)/60.)))+(oecons/3.2)+((user(6)*probeng*60.*
   +.8*.75)/3.2)
      M60L(2)=M60L(1)
      M60L(3)=M60L(1)
M60L(4)=(.030*user(6)/60.)+(user(8)*(((1.-user(2))*.75)**
+(.03*user(6)/60.)))+((user(6)*probeng*60.*.75*.75)/3.2)+
+(oecons/3.2)
      M60L(5)=M60L(4)
      M60L(6)=M60L(4)
M60L(7)=(.01*user(6)/60.)+(user(8)*(((1.-user(2))*.8)**
+(.01*user(6)/60.)))+((user(6)*probeng*60.*.7*.6)/22.)+
+(oecons/22.)
      M60L(8)=M60L(7)
      M60TD(1)=user(58)*detcons*doecons*.5/23.5
      M60TD(2)=M60TD(1)
      M60TD(3)=user(58)*detcons*doecons*.15/40.
      M60TD(4)=M60TD(3)
      M60TD(5)=M60TD(3)
      M60MOB(1)=8413.67
```

```
      M60CR=12.69
      M60Surv=2.409
      write(*,*)'***SCALED VALUES******************'
      write(*,*)'Scaled constants are '
,M60L(1),M60L(2),M60L(3),
+M60L(4),M60L(5),M60L(7),M60MOB(1),M60TD(1),M60TD(3),M60CR,
   +M60Surv

write(*,*)'***********************************************'
      Write(*,*) 'Enter the number of components considered'

      Write(*,*) 'in this execution of the program.'
      read(*,*) numc
      write(*,*) 'numbcomp = ', numc
      Write(*,*) 'Enter the Alterantives-Matrix size MxN'
      Read(*,*) m,n
      Write(*,*)'Do you need an alternatives reduction by'
         write(*,*)'performance?'
      Write(*,*)'Answer 1 for YES and 2 for NO.'
      Read(*,*) nrespon
      IF(nrespon.eq.1) then
       write(*,*)'reduction'
      call Reduce(m,n,numc,flag)
      else
c ** Reduce indicates that the user insures that all
c    alternatives  meet  specification.
      open (unit=10,file='alt.dat',status='old')
          read (10,*) ((comp(i,j),j=1,n),i=1,m)
c          write(*,*) ((comp(i,j),j=1,n),i=1,m)
c          write(*,*) comp(2,2),comp(4,3)
      endif
      nn(0)=0
      if(flag.ne.1) then
       open(unit=12,file='altcomp.dat',status='old')
        read(12,*) (l(k), k=1,numc)
        write(*,*)'L(i) is'
        write(*,*) (l(i), i=1,numc)
        do 7 k=1,numc
        nn(k)=nn(k-1)+l(k)
        write(*,*)'nn(k) is',nn(k)
        mm(k)=nn(k)
c ***** nn and mm store row numbers of the solution array.
7       continue
       endif
        budget=user(1)
      call Initial(m,numc,budget,totcost)
C******* Maximum FM found **********************
c************************************************************
c********** Save  Value *****************************
       MaxFM=FMS(1)
       Call Output(numc,m,MaxFM)
C******* Begin Excusion/Inclusion Process ******
```

```
c******* Heuristic Solution Procedure **********
       write(*,*)'The Budget and total cost
are',budget,totcost
       Costdif=totcost-budget
       write(*,*)'cost difference is ',Costdif
       IF (Costdif.le.0.0) then
       go to 999
       else
       Ob=Costdif
       write(*,*)'Amount OB is',Ob
       endif
c********* Begin Looping Procedure to find a better solution

c********* that is within budget.***************************

c ** KK is the iteration counter, the most expensive is
KK=1.
       kk=2
       Call Exclusion(numc,m,mnop,recost)
c ********** Piecewise Exclusion ***************************

c ********** Return from Exclusion *************************

c ********* Does Exclusion need to be reiterated ***********

       Call Output(numc,m,MaxFM)
       totcost=totcost-recost
       write(*,*)'New cost from reduction excl',totcost
       If(totcost.gt.budget) then
       kk=kk+1
       write(*,*)'Not enough budget for minimum component'
       write(*,*)'specifications of each type!'
       Write(*,*)'Increase budget or add cheaper
     components!'
       go to 2
       else
c ********* No more Exclusion ******************************

       Oe=budget-totcost
       write(*,*)'Money to spend!',Oe
       endif
       If(Oe.gt.0.0) then
c **** Money to BURN - Spend it, if you can !!! ************

        Call Inclusion(m,numc,mnop,totdol)
        write(*,*)'Spending',totcost,totdol
        totcost=totcost+totdol
        write(*,*)'After Inclusion new cost is ',totcost
        go to 999
       else
9       Write(*,*)' A Good Solution within Budget is found!'
```

```
         Call Output(numc,m,MaxFM)
         go to 99
        endif
999     Write(*,*) 'A Good Solution is within Budget!'
        Call Output(numc,m,MaxFM)
99      continue
2       Stop
        End
C ****** MAIN PROGRAM COMPLETE **********************
c
C
c***********************************************************
c *** INITIALIZATION Routine ******************************
       Subroutine Initial(im,nci,money,total)
       Common   user(60),comp(30,70),X(30,4),
      +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
      +M60L(8),M60TD(5),Oe,Ob,doecons,
      +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
      +kill(60),TD(60),MO(60),SURV(60),CR(60),
      +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
      +oecons,probeng,detcons,survcons,edectcons,hitcons,
      +Lflag,Survflag,Crflag,Tdflag,Mobflag
       REAL user,comp,X,kill,TD,MO,money,
      +Surv,CR,budget,Oe,Ob,doecons,totcost,FML,FMTD,FMMOB,
      +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
      +edectcons,hitcons,MaxFM,FMS
       Real IFS(12),M60L,M60TD,M60MOB,M60Surv,M60CR,IFMV
       Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

      +mm,mmm,Flag,numc,nci,im,oo,pp
c
C Order of component's alternatives in file must be low to
c high
c cost.
c This way n(k) corrsponds to highest value X(i,j).

write(*,*)'************************************************'
    write(*,*)'****     INITIALIZATION  ****************'
c Initialize variables at intial value.
          total=0.0
          IFS(1)=0.0
           do 1000 i=1,60
            kill(i)=0.0
            TD(i)=0.0
            Surv(i)=0.0
            CR(i)=0.0
            MO(i)=0.0
1000       continue
          if(nci.gt.12) then
           read(*,*) nci
          endif
       Do 16 i=1,nci
```

```
              total=total+comp(nn(i),1)
              write(*,*)'K=1,totcost=',total
              write(*,*)'comp 1 cost is',comp(nn(i),1)
16           continue
             call FMValues(nci,im,IFMV)
C** Insure the matrix FM(i,j) is filled during FM
c     subroutine.****
             IFS(1)=IFS(1)+IFMV
             FMS(1)=IFS(1)
             FMS(2)=MO(nn(9))
             write(*,*)'Best Mobility is',FMS(2)
             FMS(3)=kill(nn(11))
             call Output(inc,im,IFS(1))
 c
write(*,*)'*********************************************'
       write(*,*)'From Initialize
are',total,IFMV,FMS(1),IFS(1)
       write(*,*)'*** END INITIALIZATION **********'
             return
             end
c************************************************************
C
c*****  OUTPUT ******************************************
      Subroutine Output(onum,omain,FMMax)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totcost,FML,FMTD,FMMOB,
     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real IFS(12),M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,
    +mm,mmm,Flag,numc,onum,oo,pp,omain
      Write(*,*) '************Output*****************'
      do 44 i=1,onum
       write(*,*)'solution vector
is',nn(i),mm(i),oo(i),pp(i)
44    continue
      call FMValues(onum,omain,GoodFM)
      write(*,*)'Best FM solution was ',FMMax
      write(*,*)'Good solution is ',GoodFM
      write(*,*)'       Item   Component   binary value '
      mm(0)=0
      do 45 k=1,onum
       do 46 j=1,l(k)
         jj=j+mm(k-1)
```

```
          if(jj.eq.nn(k)) then
            X(k,j)=1.0
          else
           X(k,j)=0.0
          endif
          Write(*,*) k,j,X(k,j)
46      continue
45      continue
C Output sent to the file Tank.out
c ********************************************
        write(73,*)'Best FM solution was ',FMMax
        write(73,*)'Good solution is ',GoodFM
        write(73,*)'       Item   Component   binary value '
        mm(0)=0
        do 47 k=1,onum
         do 48 j=1,l(k)
           jj=j+mm(k-1)
          if(jj.eq.nn(k)) then
            X(k,j)=1.0
          else
           X(k,j)=0.0
          endif
          Write(73,*) k,j,X(k,j)
48      continue
47      continue
        return
        end
c**********************************************************

c ******************** FORCE MULTIPLIERS ******************
c
c*********************************************************
        Subroutine FMValues(nfmc,main,VFMV)
        Common   user(60),comp(30,70),X(30,4),
       +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
       +M60L(8),M60TD(5),Oe,Ob,doecons,
       +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
       +kill(60),TD(60),MO(60),SURV(60),CR(60),
       +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
       +oecons,probeng,detcons,survcons,edectcons,hitcons,
       +Lflag,Survflag,Crflag,Tdflag,Mobflag
        REAL user,comp,X,kill,TD,MO,
       +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

       +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
       +edectcons,hitcons,MaxFM,FMS
        Real M60L,M60TD,M60MOB,M60Surv,M60CR
        Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

       +mm,mmm,Flag,numbcomp,main,nfmc,oo,pp
         Write(*,*)'Force Mutiplier calculations follows:'
c ** Variable information
```

```
c ** Initialize FM values.
      FML=0.0
      FMTD=0.0
      FMMOB=0.0
      FMSurv=0.0
      FMCR=0.0
c****************************
      do 81 k=1,nfmc
      do 80 i=1,main
      if(i.le.mm(3).and.i.eq.nn(k)) then
        if(Lflag.eq.1) then
         write(*,*)'Going to Leth'
         Call Lethality(i,main,nfmc,FFML)
         write(*,*)'fml is ',FFML
      else
       FMLL=0.0
      endif
      FML=FML+FFML
      write(*,*)'Cum FMl from Values ',FML
c ******** changed from 7 ,11 to 5,7
      elseif(i.gt.mm(3).and.i.le.mm(5).and.i.eq.nn(k)) then
       If(Tdflag.eq.1) then
      Call TARGETD(i,main,nfmc,FFMTD)
       else
       FFMTD=0.0
      end if
      FMTD=FMTD+FFMTD
c    *******changed for example from 11 to 8 ******
      elseif(i.gt.mm(5).and.i.le.mm(9).and.i.eq.nn(k)) then
       If(Mobflag.eq.1) then
       write(*,*)'going mobile with i',i
      Call Mobility(i,main,nfmc,FFMMOB)
       else
       FFMMOB=0.0
       end if
      FMMOB=FMMOB+FFMMOB
      elseif(i.gt.mm(9).and.i.le.mm(10).and.i.eq.nn(k)) then

       if(Lflag.eq.1) then
       cgos=1.0
       do 121 mk=mm(9),mm(11)
        if(mk.eq.nn(10).or.mk.eq.nn(11)) then
         cgos=cgos*comp(mk,2)
         endif
121    continue
        kill(i)=kill(nn(1))*cgos
       FFML=kill(i)
       else
       FFML=0.0
       endif
      FML=FML+FFML
      elseif(i.gt.mm(10).and.i.le.mm(11).and.i.eq.nn(k))
```

```
     then
     if(Lflag.eq.1) then
     vgos=1.0
     do 125 mk=mm(9),mm(11)
      if(mk.eq.nn(10).or.mk.eq.nn(11)) then
       vgos=vgos*comp(mk,2)
       endif
125  continue
      kill(i)=kill(nn(1))*vgos
     write(*,*)'********************************'
     write(*,*)'********************************'
     write(*,*)'Commo kill
      rates',kill(i),kill(nn(1)),vgos,i
     FFML=kill(i)
     else
     FFML=0.0
     endif
    FML=FML+FFML
    endif
     if(i.eq.nn(k)) then
     If(Survflag.eq.1) then
    call Survive(i,main,nfmc,FMSR)
     else
      FMSR=0.0
      Surv(i)=0.0
     endif
     FMSurv=FMSurv+FMSR
     write(*,*)'cumulative surv',FMSR,FMSurv
     If(Crflag.eq.1) then
    call COMBRES(i,main,nfmc,FMCRL)
     else
     FMCRL=0.0
     CR(i)=0.0
     endif
    FMCR=FMCR+FMCRL
    write(*,*)'cumulative CR',FMCRL,FMCR
    endif
    IF(Lflag.eq.0.and.Tdflag.eq.0.and.Mobflag.eq.0) then
    VFMV=FMSurv+FMCR/float(Survflag+Crflag)
    else
c ********************************************
    VFMV=(FML+FMTD+FMSurv+FMMOB+FMCR)/
   +float(nfmc+Survflag+Crflag)
C Force Multiplier value!
    endif
80  continue
81  continue
    write(*,*)'****************FM VALUE***************'
    write(*,*)'fml,fmtd,fmmob',FML,FMTD,FMMOB,FMSurv,FMCR
    write(*,*)'FM value is ',VFMV
    write(*,*)'*****END FM CALCULATIONS ********'
    return
```

```
      end
c******************** LETHALITY *******
c
      Subroutine Lethality(k,mike,nlc,LFML)
c**   Variable Declarations
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS,LFML
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numbcomp,mike,nlc,oo,pp,k
      REAL ERF(20),ME(20),KE(20),OEF(20),time(20)
c**********************************************
c mm(l) is the row number of item l to be used
c ******** changed 7 to 5 for example ***********
c*** Engagement rate function ****
c *******************************
c **** ERF = (Rate of fire x Eng. length) / (basic load)
      ERF(k)= comp(k,3)/(comp(k,2)*user(6))
      write(*,*) 'ERF is ',ERF(k)
c **** Mission Function **********************
c ME = Reliability x [ 1-[1-PkPj]**n] or N x c
[1-[1-Pssk(1-Q)]**(N x ERF/t)
      ME(k)=user(8)*((1.-(comp(k,4)*user(2)))**ERF(k))
      write(*,*)'ME is',ME(k)
c ***** Obscured Effectiveness to Kill rate
*****************************
      time(k)=comp(k,7)+comp(k,8)
      do 10 i=8,mike
         do 11 kk=1,nlc
      if(i.eq.nn(kk)) then
      timet=timet+comp(i,7)+comp(i,8)
      end if
11    continue
10    continue
c      write(*,*)'Times are ', time(k),oecons
      OEF(k)=oecons/(time(k))
      write(*,*)'OEF is ',OEF(k)
c ******** Kill Effectiveness
************************************ c
      cei=1.0
```

```
c Ke= time x Basic load x Pssk x P(eng) x CE / (detection +
    fire)
c ***    probeng=exp(-.5*(user(13)/user(14))**2)
c              *(user(13)/(user(14)**2))
      KE(k)=user(6)*60.*comp(k,4)*probeng*cei/(time(k))
      write(*,*)'Kill Effectiveness is',KE(k)
      write(*,*)'Scaled value is',M60L(k)
      kill(k)=(ERF(k)+ME(k)+OEF(k)+KE(k))/(M60L(k))
       LFML=kill(k)
       write(*,*)'LFML is',LFML,k
       end if
8      continue
9      continue
c       write(*,*) 'lethal',LFML
       return
       end
C******END LETHAL ***************************
c
C********* TARGET DETECTION ***********
c
      Subroutine TARGETD(k,mtd,ntdc,TFMTd)
c **** Variables
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR,dtime(15)
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numbcomp,mtd,ntdc,oo,pp,k
c
c changed from 9,13 to 6,7
      write(*,*)'Welome to target detection'
      do 13 k=9,13
       do 14 lm=1,ntdc
c       write(*,*)'From TD k and nn are ',k,lm,nn(lm)
       if(k.eq.nn(lm)) then
c       write(*,*)'Comps of time ',comp(k,15),comp(k,16)
       dtime(k)=comp(k,15)+comp(k,16)
c       write(*,*)'dtime is ',dtime(k)
       scess=comp(k,14)
c       write(*,*)'Success is ',scess
       do 15 ll=1,8
```

```
         do 16 lll=1,ntdc
         if(ll.eq.nn(lll)) then
         ddtime=ddtime+comp(ll,5)+comp(ll,6)
         end if
16       continue
15       continue
         end if
       do 17 nm=9,27
          do 18 mmm=1,12
          if(nm.eq.nn(k).and.k.ne.nm) then
c
        mdtime=mdtime+comp(nm,5)+comp(nm,6)+
       +comp(nm,15)+comp(nm,16)
          end if
18        continue
17        continue
c ********** set ddt and mdt to 0.0
           ddtime=0.0
           mdtime=0.0
c          write(*,*)'Scaled value ',M60TD(1)
c *** May have to move the equation between 14, 13 continue

TgD=((user(58)*Detcons*Doecons*scess)/(dtime(k)+ddtime+
+mdtime))
          write(*,*)'tgd is ',TgD
          if(k.le.10) then
          TD(k)=TgD/M60TD(1)
          write(*,*)'ONE',M60TD(1)
          else
          TD(k)=TgD/M60TD(3)
          write(*,*)'TWO',M60TD(3)
          endif
          TFMTd=TD(k)
          endif
c          write(*,*)'Target Detection',TD(k)
14        continue
13        continue
          write(*,*)'Target Detection Fm is ',TFMTd,k
          return
          end
C **** TD END ****************************************
c
c *******  MOBILITY **********************************
      Subroutine Mobility(k,mmo,nmoc,MFM)
C ** Variables
c **** 16 and 17 are engine row numbers.
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
```

```
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS,MFM
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Real
et(30),tve(30),gw(30),rf(30),tf(30),gf(30),cf(30),
     +wf(30),traverse(30),track(30),vci(30),agi(30),
     +ema(30),mob(30),mod(30),moa(30)
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numbcomp,mmo,nmoc,oo,pp,k,i
      write(*,*)'In Mobility',k
c Should be do 12,13 but now change to 8,9
      do 28 kk=14,17
       gw(kk)=0.0
       rf(kk)=0.0
       tf(kk)=0.0
       gf(kk)=0.0
       cf(kk)=0.0
       wf(kk)=0.0
       track(kk)=0.0
       traverse(kk)=0.0
28     continue
       i=k
       write(*,*)'i and k in mobile are',i,k
c       if(i.eq.mm(6)) then
c       list=mm(5)+1
c       do 20 i=list,mm(9)
c        do 21 lm=1,nmoc
c        write(*,*)'i and nn,nmoc are', i,nn(lm),nmoc
c        if(i.eq.nn(lm)) then
c ****************** Torque *******************
        et(i)=comp(nn(9),38)*comp(nn(9),39)
        write(*,*) et(i)
c ****** Tractive Tank Effort ************************

tve(i)=(comp(nn(9),43)**2)*(comp(nn(9),25)/comp(nn(9),26))/
   +(user(18))
         write(*,*) tve(i)
c ***********  Tracking ************************************

track(i)=track(j)*(comp(j,24)/comp(j,22))*(comp(j,50)/
+user(13))

write(*,*)'Components',comp(nn(6),30),comp(nn(7),35)
          gw(i)=2000.*comp(nn(9),30)/(118.*comp(nn(6),35))
          rf(i)=comp(nn(6),33)
          tf(i)=comp(nn(6),41)
```

```
          gf(i)=comp(nn(9),32)
          cf(i)=comp(nn(9),37)/10.
          wf(i)=comp(nn(9),40)
       write(*,*)'Components
two',comp(nn(9),15),comp(nn(9),19),     +comp(nn(9),20)
c ********* Traverse mechanism *********************
 traverse(i)=comp(nn(9),15)*comp(nn(9),19)*comp(nn(9),20)
       write(*,*)'Factors
are',gw(i),rf(i),tf(i),gf(i),cf(i),     +wf(i),traverse(i)
          if(comp(j,22).ne.0.0) then
          track(i)=(comp(i,24)/comp(i,22))*(comp(i,50)/
     +user(13))
          end if
          end if
23       continue
22       continue
         end if
21       continue
c

c *******Vehicle Cone Index *******************

vci(i)=((((gw(i)*wf(i))/(tf(i)*gf(i)))+(rf(i)-cf(i)))*
     +(et(i)/30.))
         write(*,*)'VCI',vci(i)
         if(vci(i).ne.0.0) then
         agi(i)=1./(25.2+(.454*vci(i)))
         else
         agi(i)=0.0
         endif
c *********Agility ********************************
         write(*,*)'AGI is',agi(i)
         write(*,*)'sqrt comp
are',comp(nn(9),34),comp(nn(7),34)
c ******************* Maneuver ***************
c******************** and     ********************
c ******************** Mobility ***************
C

mob(i)=.15*sqrt(comp(nn(9),26))+.08*sqrt(comp(nn(9),34)*
+comp(nn(7),34))
         write(*,*)'MOB',mob(i)
         ema(i)=mob(i)*(comp(nn(9),25)/gw(i))
         write(*,*)'EMA',ema(i)
         moa(i)=mob(i)*traverse(i)
         mod(i)=mob(i)*21.33
c         mod(i)=mob(i)*track(i)
         write(*,*)'moa and mod',moa(i),mod(i)
         MO(i)=(et(i)+agi(i)+ema(i)+mob(i)+moa(i)+mod(i)+
     +tve(i))/8413.67
         MFM=MO(i)
         write(*,*)'Mobility is ',MFM
```

```
           endif
21       continue
20       continue
         Return
         End
C ************ End Mobility ****************************
C********************** SURVIVABILITY ********
c********************** More System Oriented
c*******************
      Subroutine Survive(k,ms,nsc,SFM)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numbcomp,ms,nsc,oo,pp,i,k
       Real Vul(30),PD(30),Hit(30),Heat(30),SN(30)
c********** Move-Shoot-Communicate *****************
c**********************      Sub-Systems      ********
C ********** NEED RELIABILITY FACTORS ********
c **********  Column 52 with Reliability Info. *************

        i=k
        write(*,*)'i and k are',i,k
        if(i.le.mm(2)) then
        Vul(i)=1.-(user(2)*user(20)*survcons*comp(i,52))
        PD(i)=1.-exp(-(user(11)*comp(i,4)*user(12)/(user(4)*

     +comp(i,59))))
c************** comp i,53 is exposed area **************
c************** weight is comp i,11 *******************
        tih=(Hitcons*(comp(i,53)**1.5))/(comp(i,59))
        Hit(i)=1./tih
        Heat(i)=0.0
        SN(i)=0.0
        elseif(i.gt.mm(8).and.i.le.mm(9)) then
        tih=(Hitcons*(comp(i,53)**1.5))/(comp(i,59))
        Hit(i)=1./tih
c*************** i,55 Ambient average Temp. Kelvin
************
c **************** i,54 is the wavelength
```

```
**********************
Ht=(comp(i,54)**2)*(5.7*10.**(-12))*(comp(i,55)**4)/
     +user(4)
        Heat(i)=1./Ht
c ********** bandwith matches , then b=1
***********************
SN(i)=comp(i,2)*comp(i,57)*comp(i,56)/
     +(comp(i,58)*comp(i,54))
        Vul(i)=0.0
        PD(i)=0.0
        elseif(i.gt.mm(9).and.i.le.mm(10)) then
        tih=(Hitcons*(comp(i,53)**1.5))/(comp(i,59))
        Hit(i)=1./tih
c*************** i,55 Ambient average Temp. Kelvin
c  ************
c ***************** i,54 is the wavelength
c       **********************
c ********* bandwith matches , then b=1
c ***********************
SN(i)=comp(i,2)*comp(i,57)*comp(i,56)/
     +(comp(i,58)*comp(i,54))
        Vul(i)=0.0
        PD(i)=0.0
        Heat(i)=0.0
        else
        Vul(i)=0.0
        PD(i)=0.0
        Hit(i)=0.0
        Heat(i)=0.0
        SN(i)=0.0
        end if
        Surv(i)=(Vul(i)+PD(i)+Hit(i)+Heat(i)+SN(i))/
     +M60Surv
        write(*,*) 'Survivability is',Surv(i)
        SFM=Surv(i)
        return
        end
c******* End Survivability ****************************
c*********************************************************
c*************** COMBAT RESILIENCE **********
Subroutine COMBRES(i,mcr,ncrc,CFM)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,
```

```
     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numbcomp,mcr,ncrc,oo,pp,i
c**********************************************
c ******** 50 Avail and 51 Maintenance ratio c
*****************
C ************ Need to ADD Repair parts replacement rate and

c ****** BDAR data. (FUTURE)*****************************
         CR(i)=(comp(i,50)+comp(i,51))/M60CR
         write(*,*) 'Combat Resilience is ',CR(i)
         CFM=CR(i)
         return
         end
C ******* End Combat Resilience ********************
c***********************************************************
c***********  EXCLUSION ***************************
     Subroutine Exclusion(numex,mex,mop,ckost)
c** In this routine, each component, in the previous
c solution, is  reduced to the next most expensive item. All
c other alternatives  are fixed at their previous solution
c parameters. For example,  in  iteration 2, the  main gun
c tube is reduced from alt. 3 to  alt.2.  In calculating the
c resulting FM value, all other alt.s  are fixed  at their
c previous value.
c This process insures good comparisons in reductions due to
C exclusion.
c***********************************************************
**
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numex,mex,mop,nr,oo,pp
       write(*,*)'Exclusion activated'
       nowhere=1
c      Call FMValues
```

```
c** retrieves current FM array **************
      mop=0
      do 60 k=1,numex
c*************************************************************
c**
c From highest cost per altner, work to lower cost
c sequentially,  fixing  parameters as the current holding
c parameters. Change only  one  parameter and then put it
c back at its value.
c*************************************************************
c *****
           p(k)=l(k)
           nr=nn(k)
62        if(p(k).gt.1) then
           mop=mop+1
           p(k)=p(k)-1
           nn(k)=nn(k)-1
           Call FMValues(numex,mex,FMex)
c ************ changed from k.le.3 to k.le.1 ****
           if(k.le.3) then
           diffFM(k,p(k))=kill(nr)-kill(nn(k))+
     +Surv(nr)-Surv(nn(k))+CR(nr)-CR(nn(k))
           write(*,*)'fm differences',diffFM(k,p(k)),k,p(k)
           difcost(k,p(k))=comp(nr,1)-comp(nn(k),1)
           write(*,*)'Cost difference',difcost(k,p(k))
            delFM(mop)=diffFM(k,p(k))
            delcost(mop)=difcost(k,p(k))
            write(*,*)'Differences of lethality',k
            write(*,*) mop,delFM(mop),delcost(mop)
           elseif(k.gt.3.and.k.le.5)then
           diffFM(k,p(k))=TD(nr)-TD(nn(k))+
     +Surv(nr)-Surv(nn(k))+CR(nr)-CR(nn(k))
           difcost(k,p(k))=comp(nr,1)-comp(nn(k),1)
            delFM(mop)=diffFM(k,p(k))
            delcost(mop)=difcost(k,p(k))
            write(*,*)'Differences due to detection',k
            write(*,*) mop,delFM(mop),delcost(mop)
c           elseif(k.gt.5.and.k.le.12) then
c      ******** changed to 3 and 4 for example 2 ********
           elseif(k.gt.5.and.k.le.9)then
c***********************************************************
c*******changed MO(nr) to FMS(2)*************************
           diffFM(k,p(k))=FMS(2)-MO(nn(k))+
     +Surv(nr)-Surv(nn(k))+CR(nr)-CR(nn(k))
           difcost(k,p(k))=comp(nr,1)-comp(nn(k),1)
            delFM(mop)=diffFM(k,p(k))
            delcost(mop)=difcost(k,p(k))
            write(*,*)'Differences due to Mobility',k
            write(*,*) mop,delFM(mop),delcost(mop)
            elseif(k.gt.9.and.k.le.11) then
c **** Commo effects ************************************
```

```
diffFM(k,p(k))=Surv(nr)-Surv(nn(k))+CR(nr)-CR(nn(k))+
+FMS(3)-kill(nn(k))
            difcost(k,p(k))=comp(nr,1)-comp(nn(k),1)
            delFM(mop)=diffFM(k,p(k))
            delcost(mop)=difcost(k,p(k))
            write(*,*)'Differences due to COMMO'
            write(*,*) mop,delFM(mop),delcost(mop)
            endif
            go to 62
        else
        nn(k)=nr
        endif
60      continue
        Call FMSort(mop)
        Call Searchone(numex,nowhere,mop,ccost,FMlos)
        write(*,*)'ckost is',ccost,FMlos
        Call SCuml(numex,nowhere,mop,coscum,fmcum)
        write(*,*)'Return from cumul',FMlos,coscum,fmcum
        If(FMlos.lt.fmcum) then
           ckost=ccost
           do 63 i=1,numex
            if(oo(i).ne.0) then
            nn(i)=oo(i)
            else
            nn(i)=nn(i)
            endif
63       continue
         else
          ckost=coscum
          do 64 i=1,numex
           if(pp(i).ne.0) then
           nn(i)=pp(i)
           endif
64        continue
          endif
        return
        end
C *** END Exclusion *************************************
c
C ******************* FM SORT ***************************
c Sorts FM Differences's from smallest difference to
c largest.
c ******************************************************
      Subroutine FMSort(mmop)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
```

```
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,mmop,oo,pp,Last,Least,limit
c
c
c
      Last=mmop
      Least=mmop-1
      Do 89 j=1,Least
      limit=Last-1
      Do 90 k=1,limit
c
       If(delFM(k).gt.delFM(k+1)) then
        temp=delFM(k)
        hold=delcost(k)
        delFM(k)=delFM(k+1)
        delcost(k)=delcost(k+1)
        delFM(k+1)=temp
        delcost(k+1)=hold
       endif
90       continue
         Last=Last-1
89     continue
       do 900 k=1,mmop
        write(*,*)'Sorted',delFM(k),delcost(k)
900    continue
         return
         end
c*****************************************************
C**************** COST SORT ****************************
c Sorts the costs associated with the differences from
c smallest to largest cost difference.
c ****************************************************
       Subroutine COSTSORT(mopm)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,
    +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
```

```
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,
     +mm,mmm,Flag,numex,mex,mop,nr,oo,pp,mopm,Last,Least,limit

C
c
      Last=mopm
      Least=mopm-1
      Do 89 j=1,Least
      limit=Last-1
      Do 90 k=1,limit
c
       If(cd(k).gt.cd(k+1)) then
        temp=fmd(k)
        hold=cd(k)
        fmd(k)=fmd(k+1)
        cd(k)=cd(k+1)
        fmd(k+1)=temp
        cd(k+1)=hold
       endif
90       continue
         Last=Last-1
89     continue
C
       do 910 k=1,mopm
        write(*,*)'Sorted by COST',fmd(k),cd(k)
910    continue
           return
           end
c************ SEARCH ONE ************************
c Searches for one sorted value as large or larger than
needed.
c ***********************************************
      Subroutine Searchone(nom,now,moop,cost,FMloss)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,num,mex,moop,nr,now,oo,pp,nom
c
```

```
c
       If(now.eq.1) then
         Do 92 i=1,moop
          If(Ob.le.delcost(i)) then
             cost=delcost(i)
             FMloss=delFM(i)
             write(*,*)'Search',cost,FMloss
             num=i
             call Findone(nom,num,now,moop,cost,FMloss)
             return
           else
           FMloss=9999.
           endif
92       continue
         else
          do 93 i=1,num
           if(Oe.gt.delcost(i)) then
             gain=delcost(i)
             FMgain=delFM(i)
             call Findone(num,moop,gain,FMgain)
             return
            else
            FMgain=-9999.
            endif
93         continue
          endif
          return
          end
c************** Search Cumulative **********************
c Cumulative search that sums differences.
      Subroutine SCuml(nmsc,nnow,mopp,cumcost,Cumfm)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numret,nnow,mopp,nnumex,numcum,oo,pp,nmsc

c
c
       Cumfm=0.0
```

```
          cumcost=0.0
          nnumex=0
         if(nnow.eq.1) then
            i=1
94          cumcost=cumcost+delcost(i)
           Cumfm=cumfm+delFm(i)
           write(*,*)'Cumulatives ',cumcost,Cumfm
           nnumex=nnumex+1
           cd(nnumex)=delcost(i)
           fmd(nnumex)=delFM(i)
c           If(Ob.le.cumcost) then
            numcum=i
            do 96 k=1,mopp
             do 97 jj=1,l(k)-1
              write(*,*)'CumSear diff
',delcost(i),difcost(k,jj)
              if(delcost(i).eq.difcost(k,jj).and.delFM(i).eq.
     +diffFM(k,jj)) then
              if(jj.eq.1) then
              pp(k)=nn(k)-jj
              else
              pp(k)=nn(k)-(l(k)-jj)
              endif
              write(*,*)'k and pp are',k,pp(k)
              endif
97            continue
96            continue
            if(Ob.gt.cumcost)then
            i=i+1
            go to 94
            else
            return
           endif
           else
            cumcost=0.0
            cumfm=0.0
            spend=0.0
            j=1
95            spend=spend+cd(j)
            Cumfm=cumfm+fmd(j)
            If(Oe.ge.spend) then
             cumcost=spend
             write(*,*)'Spending ',cumcost,spend
             numret=i
              do 98 k=1,mopp
               do 99 kj=1,l(k)-1
               if( d(j).eq.difcost(k,kj).and.fmd(j).eq.
     +diffFM(k,kj)) then
              if(kj.eq.1) then
              pp(k)=pp(k)+1
              else
              pp(k)=pp(k)+(l(k)-kj)
```

```
          endif
          write(*,*)'k and pp are ',k,pp(k)
         endif
99       continue
98       continue
         j=j+1
         go to 95
         else
         return
        endif
        endif
        return
        end
C ****************** FIND ************************************

c This routine identifies the alternative associated with
c the differences selected.
c
***********************************************************
      Subroutine findone(knom,knum,know,pom,dollar,Value)
      Integer*2 oo,pp
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numex,mex,mop,nr,know,pom,knum,knom
c
      write(*,*)'Findone numbers',knum,know,knom,pom
c***************************
      If(know.eq.1) then
       do 200 k=1,pom
        do 201 i=1,l(k)-1
      write(*,*)'Finding',Value,dollar,difcost(k,i),
     +diffFM(k,i)

if(dollar.eq.difcost(k,i).and.Value.eq.diffFM(k,i))then c
          oo(k)=nn(k)-i
         write(*,*)'OO is from findone',oo(k)
c *********** changes oo(k) to nn(k)
        else
```

```
          oo(k)=nn(k)
         endif
        write(*,*)'Find',oo(k)
201     continue
200     continue
        else
         do 202 k=1,knum
          do 203 i=1,nn(k)
        if(dollar.eq.difcost(k,i).and.Value.eq.DiffFM(k,i))
then              oo(k)=oo(k)+i
            else
             oo(k)=nn(k)
            endif
203         continue
202       continue
            endif
            return
            end
      Subroutine findcum
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oc(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Flag,numex,mex,mop,nr,oo,pp
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
       Integer*2 oo(12),pp(12)
c****************************
      If(nowhere.eq.1) then
       do 300 k=1,numbcomp
        do 301 i=1,nn(k)
c
if(delcost(i).eq.difcost(k,i).and.delFM(i).eq.diffFM(k,i))th
en              pp(k)=pp(k)-i
         else
           pp(k)=nn(k)
         endif
```

```
301     continue
300     continue
        else
         do 302 k=1,numbcomp
          do 303 i=1,nn(k)
       if
delcost(i).eq.difcost(k,i).and.delFm(i).eq.diffFM(k,i)
      +)then
              pp(k)=pp(k)+i
             else
              pp(k)=nn(k)
             endif
303          continue
302          continue
             endif
             return
             end
c******* END FIND ******************************
c*****************************************************

C ************* INCLUSION ***************************

      Subroutine Inclusion(mi,inum,mopp,capital)
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totalcost,FML,FMTD,FMMOB,

     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,
    +mm,mmm,Flag,numex,mex,mop,nr,oo,pp,mi,inum,mopp,nowhere
c
      nowhere=2
       write(*,*)'In inclusion',Oe,mopp
       Call COSTSORT(mopp)
       Call Searchone
       Call SCuml(inum,nowhere,mopp,capital,fmgain)
       IF(FMgain.gt.Cumfm) then
       do 71 i=1,numbcomp
        nn(i)=pp(i)
71      continue
        else
        do 72 i=1,numbcomp
         nn(i)=oo(i)
```

```
72      continue
        endif
C ************* Compare results- Chose Best ***************
c ************* Reset NN(k) ********************************
c        Call FMValues
        do 71 i=1,inum
         if(pp(i).ne.0) then
          nn(i)=pp(i)
          endif
71      continue
        return
        end
c************** END INCLUSION ********************************

c
C
C********* REDUCTION Subroutine *********************
      Subroutine REDUCE(mr,nr,numr,Rflag)
C******* This subroutine reduces the SET of Alternatives
c******* using only the LINEAR constraints of performance.
c***********************************************************
*
c Dimension and declare variables
      Common   user(60),comp(30,70),X(30,4),
     +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
     +M60L(8),M60TD(5),Oe,Ob,doecons,
     +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
     +kill(60),TD(60),MO(60),SURV(60),CR(60),
     +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
     +oecons,probeng,detcons,survcons,edectcons,hitcons,
     +Lflag,Survflag,Crflag,Tdflag,Mobflag
      REAL user,comp,X,kill,TD,MO,
     +Surv,CR,budget,Oe,Ob,doecons,totcost,FML,FMTD,FMMOB,
     +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
     +edectcons,hitcons,MaxFM,FMS
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,

     +mm,mmm,Rflag,numr,oo,pp,mnop
      Rflag=1
      k1=0
      k2=0
      k3=0
      k4=0
      k5=0
      k6=0
      k7=0
      k8=0
      k9=0
      k10=0
      k11=0
      k12=0
```

```
      Write(*,*)'sent values',mr,nr,numr
      Write(*,*)'Enter the number of alternatives for each'
          write(*,*)'component'
      Write(*,*)'in the order specified.'
      Write(*,*)'Order is Main Gun tubes, ....'
      Read(*,*) (l(k),k=1,numr)
c***** Example [3,2,3,4,3,3,2,3,3,4,3,3]
      nn(0)=0
      do 13 i=1,numr
      nn(k)=l(k)+nn(k-1)
13    continue
      Open (unit=10,File='alt.dat',status='old')
c      ii=1
c      do 12 k=1,12
      do 10 i=1,mr
       do 11 j=1,nr
      Read(10,*) comp(i,j)
11    continue
10    continue
      do 12 k=1,numr
       do 14 i=1,l(k)
      If(k.eq.1.and.i.le.nn(k)) then

if(comp(i,9).ge.user(27).and.comp(i,3).ge.user(30).and.
     +comp(i,13).ge.user(35)) then
c        comp(i,j)=comp(i,j)
       k1=k1+1
       else
       l(k)=l(k)-1
c       do 100 j=1,nr
c        comp(i,j)=comp(i+1,j)
c100    continue
c       do 101 jj=1,numr
c        ll(jj)=l(jj)+ll(jj-1)
c101    continue
        Call Delete(mr,nr,i,k,numr)
c  *** for all j
       endif
      elseIf(k.eq.2.and.i.gt.nn(1).and.i.le.nn(2)) then

if(comp(i,9).ge.user(28).and.comp(i,3).ge.user(31).and.
     +comp(i,13).ge.user(36)) then
c        comp(i,j)=comp(i,j)
       k2=k2+1
       else
       l(k)=l(k)-1
c       do 102 j=1,nr
c        comp(i,j)=comp(i+1,j)
c102    continue
c       do 103 jj=1,nr
c        ll(jj)=l(jj)+ll(j-1)
c103    continue
```

```
       Call Delete(mr,nr,i,k,numr)
c  *** for all j
       endif
      elseIf(k.eq.3.and.i.gt.nn(2).and.i.le.nn(3)) then

if(comp(i,9).ge.user(29).and.comp(i,3).ge.user(32).and.
     +comp(i,13).ge.user(36)) then
c       comp(i,j)=comp(i,j)
       k3=k3+1
       else
       l(k)=l(k)-1
c       do 104 j=1,nr
c        comp(i,j)=comp(i+1,j)
c104    continue
        Call Delete(mr,nr,i,k,numr)
c  *** for all j
       endif
      elseIf(k.eq.4.and.i.gt.nn(3).and.i.le.nn(4)) then
       If(comp(i,21).gt.user(41)) then
c       comp(i,j)=comp(i,j)
c  ** for all j
       k4=k4+1
       else
       l(k)=l(k)-1
       call Delete(mr,nr,i,k,numr)
       endif
       elseIf(k.eq.5.and.i.gt.nn(4).and.i.le.nn(5)) then
       if(comp(i,21).gt.user(40)) then
c         comp(i,j)=comp(i,j)
         k5=k5+1
       else
       l(k)=l(k)-1
       call Delete(mr,nr,i,k,numr)
        endif
        elseIf(k.eq.6.and.i.gt.nn(5).and.i.le.nn(6)) then

If(comp(i,25).gt.user(42).and.comp(i,43).gt.user(43).and.
 +comp(i,29).gt.user(44).and.comp(i,34).gt.user(45).and.
     +comp(i,26).gt.user(46).and.comp(i,27).lt.user(50))
then
c       comp(i,j)=comp(i,j)
       k6=k6+1
       else
       l(k)=l(k)-1
       call Delete(mr,nr,i,k,numr)
      endif
      elseIf(k.eq.7.and.i.gt.nn(6).and.i.le.nn(7)) then
       if(comp(i,41).gt.user(50)) then
c         comp(i,j)=comp(i,j)
          k7=k7+1
       else
       l(k)=l(k)-1
```

```
        call Delete(mr,nr,i,k,numr)
         endif
         elseif(k.eq.8.and.i.gt.nn(7).and.i.le.nn(8)) then
         if(comp(i,36).eq.12) then
c           comp(i,j)=comp(i,j)
           k8=k8+1
        else
        l(k)=l(k)-1
        call Delete(mr,nr,i,k,numr)
         endif
         elseIf(k.eq.10.and.i.gt.nn(9).and.i.le.nn(10)) then
         if(comp(i,51).gt.user(51)) then
c           comp(i,j)=comp(i,j)
           k10=k10+1
        else
        l(k)=l(k)-1
        call Delete(mr,nr,i,k,numr)
          endif
         elseif(k.eq.11.and.i.gt.nn(10).and.i.le.nn(11)) then

         if(comp(i,50).gt.user(51)) then
c          comp(i,j)=comp(i,j)
          k11=k11+1
        else
        l(k)=l(k)-1
        call Delete(mr,nr,i,k,numr)
        endif
         endif
14       continue
12       continue
c*******************************************************
       Write(*,*) 'K are
      ',k1,k2,k3,k4,k5,k6,k7,k8,k9,k10,k11,k12
      write(*,*) (l(k),k=1,numd)
       write(*,*) (nn(k),k=1,numd)
       return
       end
c*********************************************************
c******************* DELETE ******************************
       Subroutine Delete(md,nd,id,kd,numd)
       Common   user(60),comp(30,70),X(30,4),
      +FMS(12),l(15),nn(15),mm(15),cd(20),fmd(20),
      +M60L(8),M60TD(5),Oe,Ob,doecons,
      +M60MOB(16),M60Surv,M60CR,p(15),oo(15),pp(15),
      +kill(60),TD(60),MO(60),SURV(60),CR(60),
      +diffFM(20,4),difcost(20,4),delcost(20),delFM(20),
      +oecons,probeng,detcons,survcons,edectcons,hitcons,
      +Lflag,Survflag,Crflag,Tdflag,Mobflag
       REAL user,comp,X,kill,TD,MO,
      +Surv,CR,budget,Oe,Ob,doecons,totcost,FML,FMTD,FMMOB,
      +FMSURV,FMCR,FMV,oecons,probeng,detcons,survcons,
      +edectcons,hitcons,MaxFM,FMS
```

```
      Real M60L,M60TD,M60MOB,M60Surv,M60CR
      Integer*2 p,Lflag,Tdflag,Mobflag,Survflag,Crflag,l,nn,
c
     +mm,mmm,Rflag,numd,oo,pp,mnop
      Write(*,*)'In Delete',md,nd,id,kd,numd
      do 101 i=id,md-1
       do 102 j=1,nd
        comp(i,j)=comp(i+1,j)
102    continue
101    continue
       do 103 kj=kd,numd
        nn(kj)=l(kj)+nn(kj-1)
103    continue
       return
       end
c************************************************************
c ********************* END of Model ************************
```

EDITED OUTPUT (SAMPLE)

MAIN BATTLE TANK PROBLEM

************** INITIALIZATION RESULTS *************

ITEM	ALTERNATIVE	COST	FM VALUE
1	3	100K	1.354
2	3	30K	1.266
3	2	4.65K	1.700
4	2	95K	1.918
5	3	8.032K	2.560
6	2	3.66K	1.331
7	2	3K	1.331
8	2	.345K	1.331
9	2	550K	1.331
10	3	12K	1.121
11	2	3K	1.121

TOTALCOST IS $809686.70
BUDGET IS $690K
AMOUNT OVERBUDGET IS $119686.70
FM VALUE IS 1.47
FM LETHALITY IS 1.312
FM TARGET DETECTION IS 2.24
FM MOBILITY IS 1.331
FM SURVIVABILITY IS 1.424
FM COMBAT RESILIENCE IS 1.353

************** EXCLUSION RESULTS ********************

ITEM	ALTERNATIVE	COST	FM VALUE
1	2	80K	1.272
2	2	21K	1.021
3	2	4.65K	1.700
4	2	95K	1.918
5	3	8.032K	2.560
6	1	3.074K	1.040
7	1	2.420K	1.040
8	1	.230K	1.040
9	1	454.578K	1.040
10	3	12K	.934
11	1	1.741K	.934

TOTALCOST IS $682725
BUDGET IS $690K
AMOUNT TO SPEND IS $7276.00

FM VALUE IS 1.3202
FM LETHALITY IS 1.1722
FM TARGET DETECTION IS 2.24
FM MOBILITY IS 1.040
FM SURVIVABILITY IS 1.340
FM COMBAT RESILIENCE IS 1.320

************** INCLUSION RESULTS ********************

ITEM	ALTERNATIVE	COST	FM VALUE
1	2	80K	1.272
2	2	21K	1.021
3	2	4.65K	1.70
4	2	95K	1.918
5	3	8.032K	2.560
6	2	3.66K	1.104
7	2	3K	1.104
8	2	.344K	1.104
9	1	454.578K	1.104
10	3	12K	1.053
11	2	3K	1.053

TOTALCOST IS $685264.70
BUDGET IS $690K
UNDER BUDGET BY $4735.30

FM VALUE IS 1.3643
FM LETHALITY IS 1.2196
FM TARGET DETECTION IS 2.24
FM MOBILITY IS 1.104
FM SURVIVABILITY IS 1.408
FM COMBAT RESILIENCE IS 1.326

EDITED OUTPUT (SAMPLE)

FOUR COMPONENT EXAMPLE MAIN BATTLE TANK

************** INITIALIZATION RESULTS **************

ITEM	ALTERNATIVE	COST	FM VALUE
1	3	100K	1.354
2	3	30K	1.266
3	2	95K	1.918
4	2	550K	1.293

TOTALCOST IS $775K
BUDGET IS $655K
OVERBUDGET BY $120K

FM VALUE IS 1.458
FM LETHALITY IS 1.31
FM TARGET DETECTION IS 1.918
FM MOBILITY IS 1.293

***************** EXCLUSION RESULTS *****************

ITEM	ALTERNATIVE	COST	FM VALUE
1	2	80K	1.270
2	2	20.5K	1.021
3	2	95K	1.918
4	1	454.578K	1.070

TOTALCOST IS $650.078K
BUDGET IS $655K
AMOUNT TO SPEND IS $4722

FM VALUE IS 1.3217
FM LETHALITY IS 1.1455
FM TARGET DETECTION IS 1.918
FM MOBILITY IS 1.070

*************** INCLUSION RESULTS ***************

NOTHING CAN BE ADDED FOR $4722.
SOLUTION IS THE PREVIOUS SOLUTION.

EDITED ANALYST'S OUTPUT (SAMPLE)

FOUR COMPONENT EXAMPLE - ANALYST'S OUTPTUT

INITIALIZATION:

Component	Sub-model value	Cost
K_1	ERF is 1.66666E-001. ME is 54.473 OEF is 3918.367 KE is 508.779 Scaled value is 3309.64 Force Multiplier for lethality is 1.354.	Cost is $100K.
k_2	ERF is 5.000E-002. ME is 59.1233 OEF is 3840.00 KE is 288.903 Scaled value is 3307.282 Force Multiplier for lethality is 1.2663.	Cost is $30K.
k_3	Detection is 225.9771 Scaled value is 117.797 Force Multipier TD is 1.918.	Cost is $95K.
k_4	ET is 29.4 TVE is 10565.71 VCI is 39.602 AGI is 2.316E-002 MOB is 1.119 MOA is 1.119 MOD is 23.885 EMA is 260.00 Scaled value is 8413.67 Force MUltiplier MOB is 1.293286.	Cost is $550K.
Total	FMV = 1.458	Cost is $775K.

Analyst's Differences Output (Sample)

Four Component Example

Difference	Net Loss in FM	Cost Savings
1	8.197E-002	20K
2	2.183E-001	95.422K
3	2.449E-001	9K
4	2.523E-001	11.5K
5	2.562E-001	37K
6	8.967E-001	20K

Appendix D

Data Collection

Data acquisition is a critical factor in the application of a model and its implementation. The results are meaningless if the data used to execute the model is unreliable. Data has been addressed in sections of Chapters IV and V. This Appendix is used to describe, in more detail, the data collection and its use in this research's modeling process.

General Maxwell Thurman [68] discussed the importance of data in army analysis and provided a short list of where reliable data can be found. Reliable sources for performance data can be obtained from the following sources:

1. Training Activities,
2. Defence Technical Libraries,
3. Valid simulations,
4. Office of Test and Evaluation Agency,
5. Army Schools and Test Boards,
6. DOD Publications and
7. Actual combat results.

1. Training Activities. The training activities most often used as data sources are from the National Training Center (NTC) at Fort Irwin, California and the Material Development Training Activity in Fort Lewis. The NTC is a battalion sized training environment that actually puts a

single battalion against a mock soviet force. Instruments and referees collect large amounts of data that are stored in computers and analyzed. The multiple integrated laser engagement system (MILES) is used as a surrogate for actual weapons and weapon effects in combat training. The MILES data for the M1 tank is used in this research for measuring the effects of the single shot kill probability (Pssk).

2. Defense Technical Libraries. The Defense Technical Libraries (DTIC) are libraries that have access to all military or defense related research and publications as well as the military manuals for operating systems and conducting war. The DTIC is not a receptacle for data collection but data can be found in the research publications on file. Much of the data used in this research was collected from the research publications on the M1 test program provided by the DTIC.

3. Valid simulations. Validated simulations provide a broad basis for borrowing or using data that the army analysis agencies use. The Army only requires face validity for validating their simulations. Validated simulations can be found at all army analysis agencies but care must be taken because no one really knows which simulations have actually been validated. In some cases, longevity of use is mistaken for validation. Simulations do provide a wealth of

data if the researcher can afford the time to search through the inputs and the outputs of a simulation. Simulation's are generally not tailored for other individual research.

There exist both high resolution and low resolution combat simulations that can provide data. The detail and decomposition of a model dictates the level of the resolution needed to gather data. A medium resolution model, the Counterforce Potentials Model, was considered as a data source but its real data inputs and output are classified so it was not used. Some performance data on the M1 tank, used by the JANUS simulation model (a stochastic interactive force on force combat simulation developed at Lawrence Livermore National Laboratory) is used in this research.

4. Office of Test and Evaluation. The Office of Test and Effectiveness Agency (OTEA) conducts experiments and tests on army systems and reports their results to the army community. The reports are generally technical reports that can be obtained either from the agency or from the DTIC. All the unclassified operational tests conducted by OTEA on the M1 tank were reviewed and the appropriate performance data was extracted from the reports.

5. Army Schools and Test Boards. The Army schools and test boards use data to perform their combat development functions. This data is contained in computer files or in

reports but is usually in a form specific to that school's use. The data is not in a form suitable to extracting only the portions needed, so entire data files most be collected and reviewed for the appropriate performance measures. No data was collected from this source.

6. Publications. The many publications of the army and their operations research journals provide information and some data on performance issues. The Vehicle Cone Index [32] was found in one such publication and is used to describe the agility performance of the M1 tank. Reports from the testing agencies often appear in these journals. These reports are summary reports and provide some performance data gathered by the test. Armor magazine provided both information and data used in this research.

7. Combat. Recently, there have been some opportunities to gather data on equipment performance used in actual combat (Grenada and Panama). Unfortunately, this data is classified and not usable in this research.

Cost Data

Cost data is another problem source. The army material data file (AMDF) provides a component's cost listed by federal stock number. Those alternatives that already exist in the army inventory are located in the AMDF and the

current cost can be extracted. Some items are too new for the AMDF. These item cost's were obtained directly from the Tank and Automotive Command in Warren, Michigan. Items that are considered future items had their costs approximated. A "best guess" approximation was obtained using straight line regression and extrapolation from current alternatives to the future alternative. The 120 MM Energized gun is one such cost approximation using the data for the other type main gun tubes in the inventory.

Cost data for munitions and crew were left out of the model. These costs are not factored into the design of a weapon system directly; therefore, they were not used in the model.

Costs for the turret assembly, armor plating, and wiring harness are also left out of the model since there currently exits no alternatives for those components [63]. The budget was adjusted to reflect the absence of these three components that are design items of a weapon system.

Combat Variables

The sources of data are available but the researcher must decide which combat variables to include in the model. The decomposition of the system and the Force Multiplier provide the variable lists. The combat variable breakdown is illustrated in Figure D.1

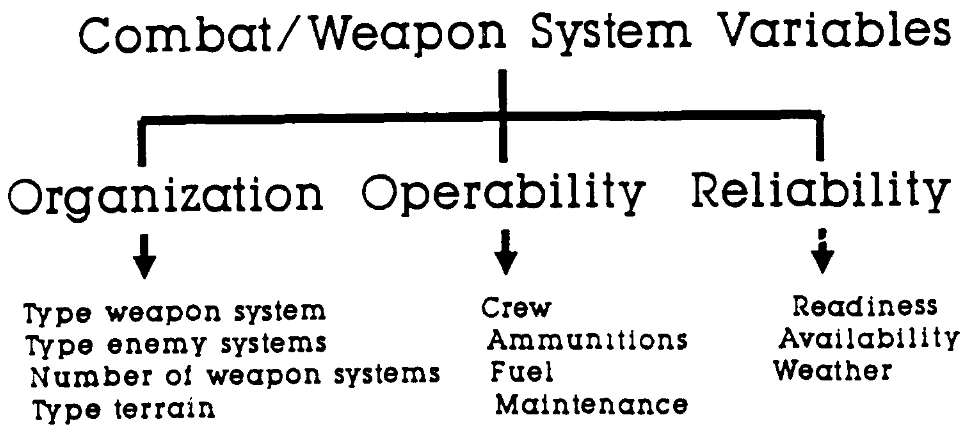

Figure D-1 Categories of Variables

The criteria for warfare [FM 100-5,83] again illustrates the variables and their relationship to combat specific issues (Table D-1).

Table D-1

Criteria of Warfare (FM 100-5, 1982)

METT-T	Mission, enemy, troops available, terrain, time available
OCOCA	Observation, concealment, obstacles, cover, avenues of approach
Principles of War (Command and Control)	Mass, objective, surprise, simplicity, offense, unity of command, security, economy of force

These criterion of warfare are considered both in the level of decomposition and in the mapping of a weapon system's components into the attributes of the Force Multiplier. This mapping dictates the amount of representative data required. The total mapping for a weapon system as used in this research was illustrated in Appendix A and will not be repeated here. Figure D-2 shows how the data inputs are utilized and transferred within the main sections of the solution methodology.

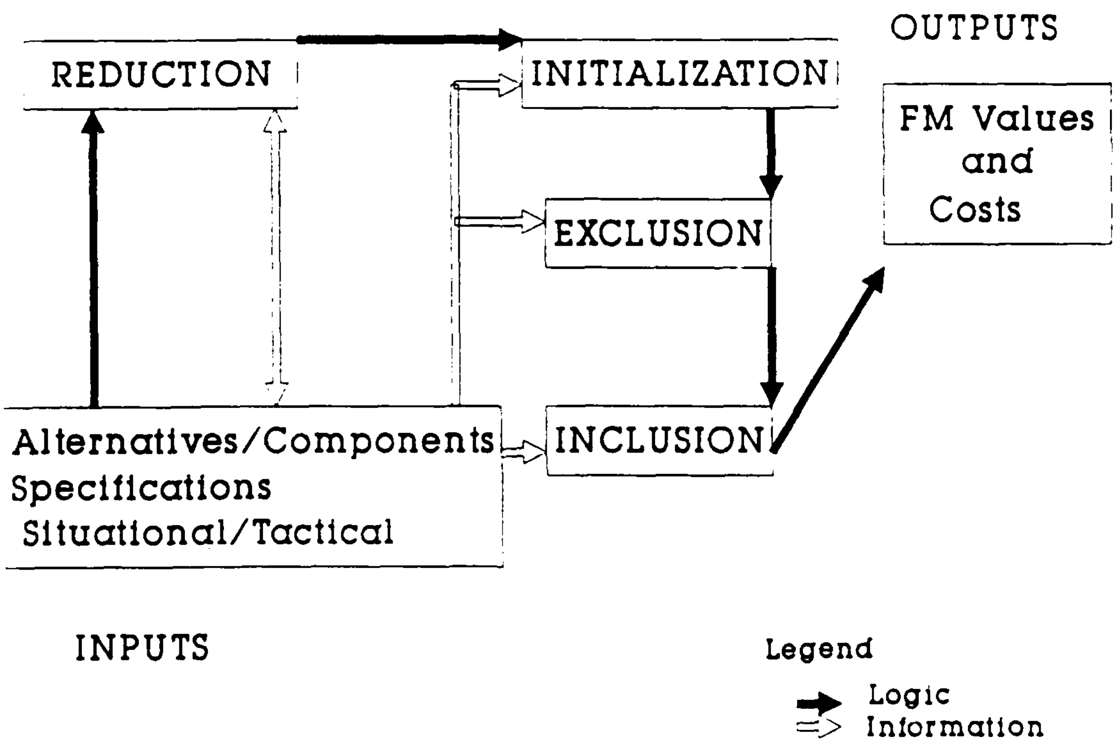

Figure D-2. Data Transfer

Data Used in Model

The data, used in the model, are compromised from two related but different files: the analyst file (Analyst.dat) and the weapon system's component/alternatives file (Alt.dat). The analyst's file contains the situation or tactical information for the weapon system that impacts upon both a weapon system and its component parameters. The component/alternative's file lists all this research's defined parameters for all the alternatives of each component for a given weapon system. The cost data is found in the component/alternative's data file.

User Situational/Tactical Inputs

item	units
Budget	dollars
Enemy P(kill)	0<Pk<1
Enemy P(hit)	0<Ph<1
Width of search path	meters
Area of operations	square meters
Engagement length	seconds
Subjective reliability of mission	0<M<1
Number of weapon systems	integer>0
Degradation Factor	0<D<1
Obscurity Factor	0<O<1
Observer-target rate	KPH
Target density	targets per square meter
Range	meters
Sweep angle	degrees
Alpha rate	500, 1000, or 1500
Velocity Code	stationary or motion ss,sm,ms,mm
Human reliability	0<Hr<1
Road Friction	real number
Number of Glimpses	integer
Line of Sight	0<LOS<1
Posture code	open or defilade
Engagement type	head or flank
Time length	hours

Operating time	hours
Priority targets	tanks or other
Search length per target	seconds

User Specifications

- Muzzle Velocity
  - main gun
  - auxiliary gun
  - coax gun
- Basic Load
  - main gun
  - auxiliary gun
  - coax gun
- Power for main gun
- Target type J (J=1,2)
- Maximum Effective Range
  - main gun
  - auxiliary gun
  - coax gun
- Target detection power
- Maximum range
  - Laser range finder
  - Thermal sights
  - Passive sights
- Horsepower
- Gear Ratio
- Miles per gallon
- Cruise range
- Maximum speed
- Power of engine/transmission
- Track force
- Communications power
- Heat given off by engine
- Armor thickness
- Maximum communication distance
- Minimum repair parts
- Verticle climb
- Ditch width
- Acceleration
- Grade of service (Communications)
- Power output (communications)

Example User File

Example of User Data
(Tactical data and Specifications)
650000.0
0.5
0.5
1000.0
160000.0
60.0
1.0
54.
1.
1.
25.
1.0
1000.
45.
1000.
1.
1.
.07
10.
1.
1.
1.
1.
1.
1.
60.
1500.
1900.
1900.
35.
850.
10000.
3.
2000.
2500.
1500.
5.
1000.
1000.
1000.
900.
3:1.
1.
210.
35.
10.
10.

Specifications (Continued)
10.
100.
2.
10.
1.
18.
31.
5.
.7
10.
10.

Component/Alternatives Data Code

Item	Position
Cost	1
Rate of fire/GOS	2
Basic load	3
Pssk	4
Time to detect	5
Time to aim	6
Time to fire	7
Time to reload	8
Muzzle velocity	9
Radius/depth of penetration	10
Weight	11
Maximum effective range	12
Maximum range	13
Prob. success	14
Time to acquire	15
Time to identify	16
Time to traverse	17
Time to operate	18
Slew rate	19
Traverse rate	20
Effective track range	21
Elevation	22
Azimuth	23
Tracking rate	24
Horsepower	25
Max speed	26
Acceleration	27
Ground Pressure	28
Fuel Capacity	29
Weight	30
Gross area	31
Grousser Factor	32
Number of roadwheels	33
Operating range(distance)	34
Area of track shoe	35
Number of shock per sets	36
Ground clearance	37
Length of Track	38
Horsepower per tons	39
Weight Factor	40
Track Factor	41
Max Torque	42
Gear ratio	43
Max Gradient	44
Max trench obstacle	45
Max verticle obstacle	46
Average engine temperature	47

Item	Position
Average engine noise level	48
Area of Engine/Transmission	49
Availability	50
Maintenance Ratio	51
Max effective trans range	52
Exposed Target Area	53
Average wavelength	54
Temperature (operating)	55
Power Out	56
Bandwidth	57
Max. Wavelength	58
Weight	59

Example Component/Alternative Data File

Example Number of Alternatives per Component

3

3

2

2

3

2

2

2

2

3

2

Main Gun Example Data

63000 7 55 .8 1 1 1 2 1501 35 2500 2000 3000 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .8
.5 1. 4.8 60 0 0 0 0 58

80000 5 48 .85 1 1 .6 2 1650 38 4000 2500 3500 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .9
.9 1.
4.8 50 0 0 0 0 60

100000 4 40 .88 1 1 .45 2 1950 45 5000 3000 4000 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
.91 .9 1
4.8 49 200 0 0 0 60

Example Auxiliary Gun Data

18500 500 1000 .2 2 1 2 1 2840 1 126 8066 1308 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .7

.5 1.

4.8 50 0 0 0 0 58

21000 600 900 .25 2 1 2 1 2930 1 87 6700 1600 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

.71 .5 1.

4.8 50 0 0 0 0 59

30000 200 600 .51 .15 .12 1 1.5 1345 1 105 2500 3000 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0

.72 .8 1.0 5. 60 0 0 0 0 60

Example Machine Gun Data

2500 600 11400 .189 2 20 2 20 990 1 8 300 2635 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

.62 .71

1. 2.1 0 0 0 0 0 123

4650 750 11400 .2629 2 10 2 10 745 1 10 900 3725 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

.62 .71

1.0 2.1 0 0 0 0 0 120

Example Primary Sight Alternative's Data

75000 0 0 0 0 0 0 0 0 0 0 0 0 .5 22 1 22 1 4800 45 500 75 1
67

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .92 .92 1.0
1.0

20 0 0 0 0 650

95000 0 0 0 0 0 0 0 0 0 0 0 0 .8 18 1.6 18 1.6 4800 45 500
75 1 67 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .95
.95 1.0 1.0 20 0 0 0 0 700

Example Secondary Sights Alternative Data

6004 0 0 0 0 0 0 0 0 0 0 0 0 .15 30 10 30 10 1 1 600 1 360
120
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .75 .7 1.0
1.0
30 0 0 0 0 20

6700 0 0 0 0 0 0 0 0 0 0 0 0 .2 21 7 21 7 1 1 2000 1 360 8
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .78 .8 1.0
1.0
28 0 0 0 0 28

8032 0 0 0 0 0 0 0 0 0 0 0 0 .25 20 6 20 6 1 1 2000 1 360 35
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .8 .9 1.0
1.0
25 0 0 0 0 25

Example Track Set Alternative's Data

3074 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 30 14 1
13.5 1 1 1 1 1 115 1 1 1 1 1 .208 1 1 1 1 1 1 1 1 .5 .5 1.0
0 0 0 0 0 0 0

3660 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 25 14 1
1 13.327 1 1 1 1 122 1 1 1 1 1 .206 1 1 1 1 1 1 1 1 .83 .79
1.0 0 0 0 0 0 0 0

Example Fuel Set Alternative's Data

2420 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1

504.4 17 1 1 1 504.4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 .5 .5

1. 0 0 0 0 0 0 0

3000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1

508 17 1 1 1 508 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 .5 .5 1.

0 0 0 0 0 0 0

Example Power Set Alternative Data

230 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 28 100 220 1 1 .6 .6 1. 0

0 0 0 0 0 0

344.70 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 24 300 650 1 1 .6 .6 1.0 0 0

0 0 0 0 0

Example Drive Set Alternative Data

(Engine/Transmission)

454578 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1500 45 6.1 13.327 508 61 50479 1 1 .525 122 12 19 1.05
25.4 1 .208 3952 4.3 60 23 19 300 23 2500 .85 .9 1. 25
60 300 1 1 1 62

550000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2000 50 5 13.1 508 62 50479 1 1 .547 122 12 20 1.05
28 1 .208 3952 4.3 65 25 21 325 23 2500 .86 .91 1. 26.
50 300. 1 1 1 63

Example Radio Set Alternative Data

1941 .60 10 8 5 5 50 920 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .6 .5 1.0 1. 25.
1. 7. 12. 920. 20.

8816 .75 30 40 3 3 50 920 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .65 .55 1.0
1.0 25. 1. 6.5 25. 920. 35.

12000 .92 49 60 1 1 25 2320 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .8 .8
1.0 1. 25. 1. 6. 35. 2320. 40.

Example Intercom Set Alternative Data

1741 .75 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .75 .6 1. 1. 0 0 0
0 0 5.

3000 .9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .9 .82 1. 1. 0 0 0
0 0 5.

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